THE UNIVERSITY OF ALBERTA

SOME FACTORS INFLUENCING THE PHYSICAL PROPERTIES OF BUTTER

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The undersigned hereby certify that they have read and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled

SOME FACTORS INFLUENCING THE PHYSICAL PROPERTIES OF BUTTER

submitted by L. M. McKnight in partial fulfilment of the requirements for the degree of Master of Science.

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ABSTRACT

The hardness of non-printed butter from five creameries in the Edmonton area was found to vary considerably in that the butter made in some factories was consistently much harder than that from others.

Contrary to impressions created by some manufacturers, margarine is not always spreadable at refrigerator temperatures and, in fact, some brands are comparable in hardness to continuously made butter. By the use of polarized light microscopy, the brands of margarine found to be hardest possessed a crystalline structure similar to continuously made butter. The similarity of the softening points of butterfat and margarine oil and the melting point of the high melting glyceride fractions in each product indicated that similar methods may be used to reduce the hardness of both products.

Precrystallization of butterfat concentrate in a continuous buttermaking process was carried out to reduce the hardness of the continous type butter. Continuous precrystallization, using the laboratory continuous buttermaking machine with a precrystallizing unit was very effective in reducing butter hardness with no apparent defects in texture or appearance. Butter from commercial batch precrystallized concentrate showed a grainy texture and an increased oiling-off percentage. Polarized light microscopy revealed very large crystals in butter from batch precrystallized concentrate. No explanation can at present be offered for this.

Homogenizing butter in a Benhil Microfix unit was shown to be effective in reducing the hardness of butter, particularly after a period of storage. The butter after homogenizing did not regain its original hardness during four weeks storage, but remained much softer than butter not homogenized. By the use of polarized light microscopy, a reduction in the quantity of crystalline fat was observed. The amount of solid fat decrease and/or disruption of the primary crystal structure are suggested as major factors in hardness reduction and lack of re-setting.

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SOME FACTORS INFLUENCING THE PHYSICAL PROPERTIES OF BUTTER

INTRODUCTION

The physical properties of butter have been the subject of intensive investigation in recent years. Much of this work has been directed toward decreasing the hardness of butter in order to improve its spreadability on bread. The increased use of refrigeration in the household and also the development of continuously made butter which is much harder than conventional (churned) butter, have focused attention on the need for improvement in the spreadability of butter.

Recent published research in this field indicates that the plastic properties of butter may be favourably modified by processing techniques. However, such process alterations must be able to bring about a substantial improvement in spreadability at a minimum increase in cost if they are to receive acceptance. deMan (1961) considered that the following processes may meet those requirements and are therefore worthy of further investigation:

(1) thermal treatment of the cream;

(2) mechanical treatment of the butter;

(3) thermal treatment of the butter;

(4) a combination of two or all of the aforementioned treatments.

Continuous methods for buttermaking have been introduced with varying degrees of success during the past twenty five years. These processes are of two general types, those developed in Europe and

Australia which make butter directly from cream, and those introduced in the United States, using butteroil obtained from the mechanical destabilization of the cream emulsion. The introduction of such new methods of buttermaking, especially those based on the use of butteroil, has further aggravated the still largely unsolved problem of excessive hardness of butter. In the present investigation two processes, pre-crystallization of butterfat in continuous butter-making, and homogenization which is applicable to both conventional and continuously made butter, were investigated to determine their effectiveness in the reduction of hardness and improvement of spreadability.

REVIEW OF LITERATURE

Structure and Properties of Butter

"The physical structure of butter represents the manner in which the chemical components - fat, water, curd, air - are distributed, intermingled, juxtaposed and linked together" (King, 1955b). "The properties of the butter are closely connected with its microstructure. The following relationship is therefore valid:

Manufacturing method ⟶ Structure of the butter ⟶ Properties of the butter" (King, 1952).

Butter made by the conventional (churn) method is a disperse system with the liquid portion of the free fat as the continuous phase in which are dispersed fat globules, fat crystals, serum droplets and air bubbles. The type of continuous process[1)] studied here produces a more simplified water in oil emulsion than conventional butter i.e. fat crystals and serum droplets embedded in the liquid butterfat (Wood & deMan, 1956).

According to King (1947) the average diameter of the butterfat globules of conventional butter is 3 - 4 μ and the globular butterfat content varies between 2 and 46% with an average of 30%. King also reported that the diameter of the smallest water droplets is below 1 μ and the upper limit is controlled by the amount of working received by the butter. Muller (1952) set arbitrarily the upper limit for water droplets at 30 μ. Conventional butters

1) a process known as Gold'n Flow, copyrighted by the Cherry-Burrel Corp., Cedar Rapids, Iowa.

are reported to contain varying amounts of gas. Thomsen (1955) stated that a gas content of 4% is a reasonable average.

King (1952) showed that the continuously made butter has few fat globules and the fat crystals vary considerably in size. According to Wood & deMan,(1956) continuously made butter (Gold'n Flow) was characterized by the absence of fat globules, the presence of larger fat crystals and a much finer dispersion of moisture droplets than occurs in conventional butter. Of 14 samples of such butter deMan & Wood, (1958a) reported an average gas content of 0.1% which is much less than in conventional butter, cf. Thomsen (1955).

The physical properties of conventional and continuously made butter are a result of their characteristic physical structure, with the butterfat crystallization phenomena being mainly responsible for the different structures in the two types of butter. This review will consist of a survey of the literature on some aspects of fat crystallization phenomena, the influence of these phenomena on the structure and properties of conventional and continuously made butter, and the influence of mechanical treatment on butter properties.

Factors Influencing Structure and Properties of Butter

Influence of fat crystallization. Butter possesses characteristic properties; it is plastic and therefore spreadable. There are three conditions, which are essential for plasticity in a material (Bailey, 1951).

(1) It must consist of two phases. One of the phases must be solid and the other must be liquid.

(2) The solid phase must be in a state of sufficiently fine dispersion for the entire mass to be effectively held together by internal cohesive forces.

(3) There must be a proper proportion between the two phases.

At body temperature all the fat in butter is completely liquid but at lower temperatures, the fat is a mixture of solid and liquid components. Hannewijk & Haighton (1957) found that only at very low temperature i.e. -30°C is butterfat completely solid. The proportion of liquid fat in the free fat varies according to:

(1) the composition of the fat;

(2) the manufacturing method applied, and

(3) the temperature of the butter (King, 1955a).

The chemical composition of milk fat is subject to wide seasonal variation (Cox & McDowall, 1948; Hansen & Shorland, 1952; McDowell, 1954; Riel, 1955; Wood, 1956; Wood & Haab, 1957). It has been shown (Coulter & Hill, 1934) that large differences in unsaturation and chain length of the fatty acids in butterfat contribute to excessive hardness of winter butter. Mulder (1956) and Rishoi & Sharp (1938) using dilatometric measurements on cream showed that more fat crystallized in winter than in summer cream, at the same temperature. The seasonal differences indicate relatively large variations in the higher melting glycerides, whereas the cooling treatment variations

occur mainly at lower temperatures indicating an increase in lower melting point crystals (deMan & Wood, 1959b). These investigators found that differences in solid fat content parallel the differences in hardness of butter. Dolby (1949) estimated that changes in composition of the butterfat were responsible for some 80% of the seasonal variation in hardness of New Zealand butter. Bailey (1950) stated that crystals composed in large part of high melting glycerides possess more rigidity and hence greater stiffening power than crystals of lower melting glycerides.

A larger proportion of fat solidifies with rapid cooling than with slow cooling (Mulder, 1953). Mulder stated that rapid cooling gives more crystallized fat than slow cooling because with rapid cooling the high melting glycerides incorporate some of the low melting glycerides in the crystal lattice. This inclusion of lower melting glycerides in the crystal lattice (called mixed crystal or solid solution formation) results in the presence of more crystallized fat at any one temperature than would have been the case if the fat had been cooled slowly. The presence of a large number of closely related glycerides in butterfat is an ideal condition for the occurrence of mixed crystals. This factor is assumed by some workers to be a main cause of differences between slowly and rapidly cooled butterfat. Evidence in favour of this assumption has been obtained by dilatometry (deMan & Wood, 1959b; Hannewijk & Haighton, 1957; Mulder, 1953) and by calorimetry (Phipps, 1957). Coulter & Combs (1938) found that conventional butter hardness was increased by the

following three factors: cooling of the cream to a low temperature, rapid cooling to below $40^{\circ}F$, and churning at a low temperature. Dolby (1941b) showed that of the following factors - type of pasteurizer, rate of cooling after pasteurization, temperature during holding and churning, temperature of wash water and amount of working - only the rate of cooling cream after pasteurization had any marked and consistent effect on the hardness of butter; the rapidly cooled cream yielding harder butter.

When a substance crystallizes from solution a rapid temperature decrease with adequate agitation favors the formation of small crystals. Crystals with maximum diameter 1 - 2 μ are formed when butterfat is rapidly cooled (deMan & Wood, 1959c). Slow cooling of the same butterfat, without agitation, was found to favour the formation of large crystals with diameters up to 40 μ. In the conventional method of buttermaking, the fat is in the globular form when the cream is cooled. As a consequence, the crystals can not exceed the diameter of the globule and are usually much smaller. The fat crystals in the free fat of conventional butter have been reported to be as small as 0.1 μ (Van Dam & Burgers, 1935). Cooling in the continuous method takes place in a few seconds so that butterfat leaves the chiller in a supercooled state. Crystallization is an abrupt phenomenon, but fat easily passes into the supercooled state, the effect of which is a retardation of crystallization (Bailey, 1950). Only after an induction period does the supercooled fat start to

crystallize and then crystallization proceeds rapidly. It is held probable that after treatment in the chiller unit, crystallization takes place by enlargement of existing crystals and not by the formation of new crystals (deMan, 1960a). The large size of the fat crystals in continuously made butter, up to 30 - 40 μ in diameter, can contribute to the enhanced firmness of this butter.

Mulder (1953) has shown that besides the influence of the rate of direct cooling both re-crystallization and step-wise cooling may profoundly affect the solid fat content and consequently the hardness of butter. Re-crystallization as the result of cooling, holding, and subsequent warming to a temperature at which some solid fat still exists and then re-cooling, results in a lowering of the solid fat content of cream (Mulder, 1953) and butterfat (deMan & Wood, 1959b). deMan & Wood (1958b) had shown earlier that the hardness of both conventional and continuous butter was lowered by tempering for two weeks at 22.5° C. Step-wise cooling also produces a lower solid fat content of cream (Mulder, 1953) and butterfat (deMan, 1960b). According to Mulder the effect of step-wise cooling may be explained on the basis of the mixed crystal hypothesis. The portion of the fat which solidifies at the first break in a step-wise cooling was reported to have no further effect on the glycerides, which are still liquid, hence reducing mixed crystal formation (Mulder, 1953). Furthermore this investigator pointed out that glycerides still in the liquid state after the first break in cooling, will crystallize

less readily than when the fat is cooled directly.

Cooling of the oil concentrate in the modern manufacture of margarine is carried out in a form of heat exchanger called a Votator (Bailey, 1951). This is similar in principle to the Cherry-Burrell butter making equipment. Margarine manufactured in the Votator is reported to be harder, more brittle and less spreadable than is desired and known as "heavy" or "thick" on the palate (British Patent, 1951). According to the claims in the patent application the thickness and brittleness of margarine is caused substantially by all the solid components of the fat being in the form of minute crystals. It has been claimed (British Patent, 1951; U. S. Patents, 1956a, 1956b) that by the previous separation of the higher melting point constituents of the fat blend (precrystallization), the thick characteristic may be reduced. The degree to which fat is cooled and agitated before final chilling was reported to control the thinness and spreadability of the margarine produced. Lower cooling temperatures were found to produce thinner and more spreadable margarine, while vigorous agitation and/or lower cooling temperatures was found to prevent growth of crystals. The methods described in these patent applications, for obtaining precrystallization of the fat, involved recirculation of a portion of the crystallized margarine through an agitated chamber, where it was mixed with the fat blend entering the Votator unit. The size of the precrystallizing chamber permitted

sufficient residence time to obtain precrystallization of the higher melting glycerides.

Immediately after the working of butter is finished, it is described as being a kind of soft unctuous mass, but after setting or time-hardening it is much harder and butterlike (Mulder, 1949). According to this worker the hardness after setting may be as much as twenty times greater than before setting. Prentice (1953) has also reported considerable hardness increases during setting. Two factors have been proposed to be responsible for the hardening effect: (1) the completion of unfinished crystallization of the fat and (2) changes of a thixotropic character. Completion of the unfinished crystallization increases the proportion of solid to liquid fat, whereas thixotropy involves changes in spatial arrangement of the dispersed particles. Sproule (1957) has inferred that setting is caused solely by continued crystallization, while Mulder (1949) pointed to the importance of thixotropy in the setting process. However, because of increases in hardness of butter held at the temperature prevailing at the end of churning, (deMan & Wood, 1958b) and in butter held above the final churning temperature (Storgards, 1940), continued crystallization cannot be the sole cause of the setting effect.

deMan & Wood (1958b) report that the hardness of butter made by the continuous method is consistently higher than that of conventional butter. Similar seasonal variations were found for both types and were greater than differences between the two butter types

at 17°C. The hardness depends on such factors as proportion of solid to liquid butterfat, and size, shape and mode of dispersion of the solid particles, all of which play a role in the hardness differences between the two butters. The crystal state of continuous butter also influences the oiling-off tendency. deMan & Wood (1958c) stated that butter made by the continuous process has a consistently greater tendency to oil-off at 25° or 28°C than conventional butter. Seasonal variations were reported to show the same trend for both butter types, and were considerably greater within the type than the differences between corresponding samples of the two types. Conventional butter has been reported (deMan & Wood, 1959a) to show a higher degree of setting than continuous butter. It is reported (deMan & Wood, 1958d) that the higher degree of setting is due to a greater number of small crystals in conventional butter. Setting was also reported to be influenced by initial hardness. Butters with a high initial hardness exhibited greater setting.

Influence of mechanical treatment. Mechanical treatment of butter, which has been allowed to set, during printing (deMan & Wood, 1959a ; Hueber & Thomsen, 1957), reworking in a churn, (Dolby, 1941a; Mulder, 1949) and blending, (Prentice, 1953) results in a lower butter hardness that recovers during subsequent storage but never completely regains the original value. Gentle re-working, such as that received by the butter in a printing machine, often causes a sufficient disruption of the structure of conventional butter to increase the

size of moisture droplets (Fisker, 1958), and a significant lowering of gas content (deMan & Wood, 1958a). The enlarged moisture droplets result frequently in leakage of moisture from the butter and a decrease in quality. Mixing machines or butter homogenizers have been developed in Europe for re-working of cold-stored butter before printing, primarily for improving the moisture distribution (Fisker, 1958). A number of workers in Europe (Dibbern & Koenen, 1956, 1957, 1959; Koenen, 1958, 1959; Mohr et al. 1958a, b; Mohr & Oldenburg, 1959; Pedersen, 1960; Petersen, 1960) have studied the influence of homogenization on the properties of different types of butter. Dibbern & Koenen (1956, 1957), Mohr et al. (1958a), Pedersen (1960) and Petersen (1960) found that homogenization of cold-stored conventional butter decreased hardness and improved moisture distribution, while Mohr et al. (1958b) and Pedersen (1960) found that homogenization of freshly churned butter improved moisture distribution but had very little effect on reduction of hardness.

Pedersen (1960) is the only investigator to attempt an explanation of the principles involved in butter homogenization. The explanation advanced states that homogenizers constructed according to the rotor principle, cut the butter into paper thin slices and subsequently work them together again. This removal of a paper thin slice over the entire surface of the column of butter being forced into the rotor head was reported to result in the first subdivision of the

moisture droplets, and the second subdivision taking place as the rotor turns and the thin slice is deposited on the surface of the outgoing butter. According to these investigators, the clearance between rotor and rotor housing is 1mm, which naturally limits the thickness of slice being removed and deposited. Homogenization is reported (Pedersen, 1960) to have no influence on the air content of the butter irrespective of the butter temperature.

METHODS AND MATERIALS

Precrystallization

Precrystallization of the butterfat concentrate in a continuous buttermaking process was attempted by three methods:

(1) continuous method using a cooling coil;

(2) batch or discontinuous method;

(3) continuous method using a precrystallizing unit.

Preliminary trials with the continuous method using a cooling coil and the batch or discontinuous precrystallizing procedure were carried out using a laboratory continuous buttermaking machine, developed in this department (Wood & Thornton, 1956). Some further trials using the batch method were adapted to existing commercial practice using a Cherry-Burrel continuous buttermaking machine installed in an Edmonton creamery. Final precrystallization trials were made with the laboratory continuous buttermaking machine, equipped with a precrystallizing unit.

In the continuous method using a cooling coil, the temperature of the butterfat concentrate in the mixing tank was maintained in the range 100° - 105°F. During processing the butterfat concentrate was cooled to the required temperature by passing it through a 3/8" O.D. aluminum coil immersed in a vessel of water. The water was maintained at the required temperature by periodic addition of either cold water or ice. The temperature of the butterfat concentrate was measured at

the exit end of the coil just before the entrance to the chilling unit. Butter samples were taken before and after precrystallization. Cooling the butterfat concentrate in the batch or discontinuous precrystallizing method, using the laboratory machine, was achieved by suspending a vessel containing the concentrate in a tank of cool water. The concentrate was stirred continuously during cooling and intermittently during holding, until the desired temperature had been maintained for from 30 to 60 min., after which the butterfat concentrate was transferred to the mixing tank of the machine and pumped directly to the chilling unit. Samples of butter representing non-precrystallized and precrystallized concentrate were taken after stabilization of operating conditions.

The batch precrystallizing method was applied to the commercial continuous buttermaking operation with a minimum alteration of normal procedure. The temperature of the butterfat concentrate, which was stored in a standardizing tank, was lowered to 90°F in approximately two hr. with agitation and then held without agitation a further 9 to 10 hr. and either processed directly at 90°F or cooled further with agitation in 2 to 3 hr. before processing. The remaining butterfat concentrate was then heated in the standardizing tank to the normal temperature of 100° to 105°F. After the operation of the equipment became stabilized, butter samples representing non-precrystallized concentrate were taken.

A modification of the laboratory continuous buttermaking machine

(Figure 1) was used in all trials of the precrystallizing method, in which a precrystallizing unit was used. A flow diagram of this process is shown in Figure 2. The temperature of the butterfat concentrate was maintained in the normal processing range of 100° to 105°F in the mixing tank A. The butterfat concentrate was pumped through a line from a to b by pump E_1 to the precrystallizing unit C. When chamber C was filled the concentrate was forced through line cd to the chilling unit B. The chilled concentrate then passed from B through line ef to the texturator D where crystallization occurred and the final butter worked by its passage through the texturator plate g. Passage of the butter through the texturator plate and tapered outlet resulted in a pressure build-up in the system. This pressure aided by pump E_2 forced a portion of the chilled concentrate through the branch line hk, to the precrystallizing unit C. The chilled butterfat concentrate re-circulated through hk was mixed by vigorous agitation with incoming warm concentrate from the mixing tank A to precrystallize the butterfat concentrate. The first butter emerging from D is of course re-processed as it has not been precrystallized. The elements of the stainless steel precrystallizer and agitator are shown in Figure 3. The outer casing (right center) was fitted with the stationary section of the agitator (extreme left). The stationary section of the agitator was fabricated from a stainless steel tube with regular sections cut and folded-in directly opposite each other. The rotating shaft (left center) has blades welded on to the shaft

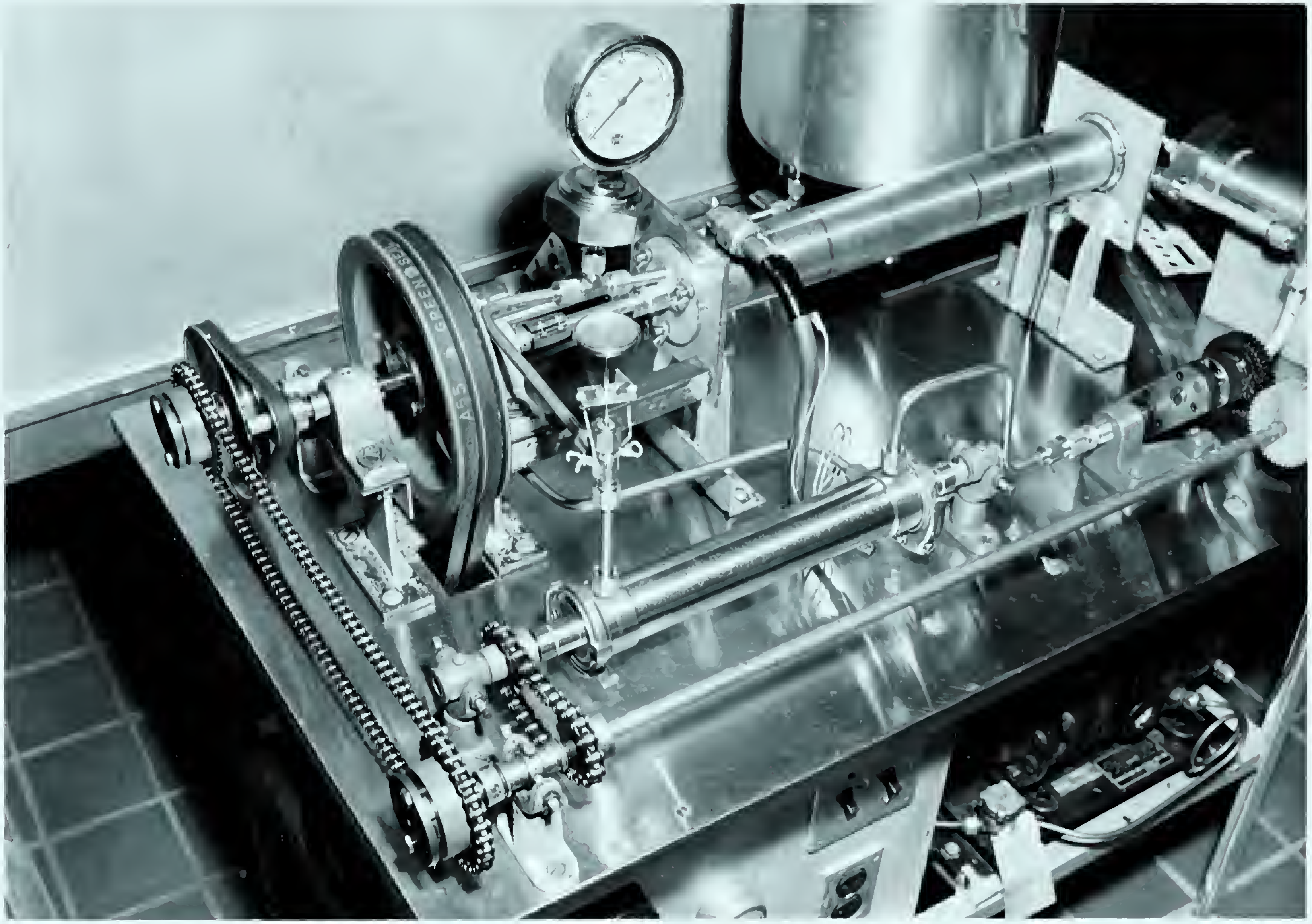

Figure 1. Laboratory continuous buttermaking machine showing attached precrystallizing unit.

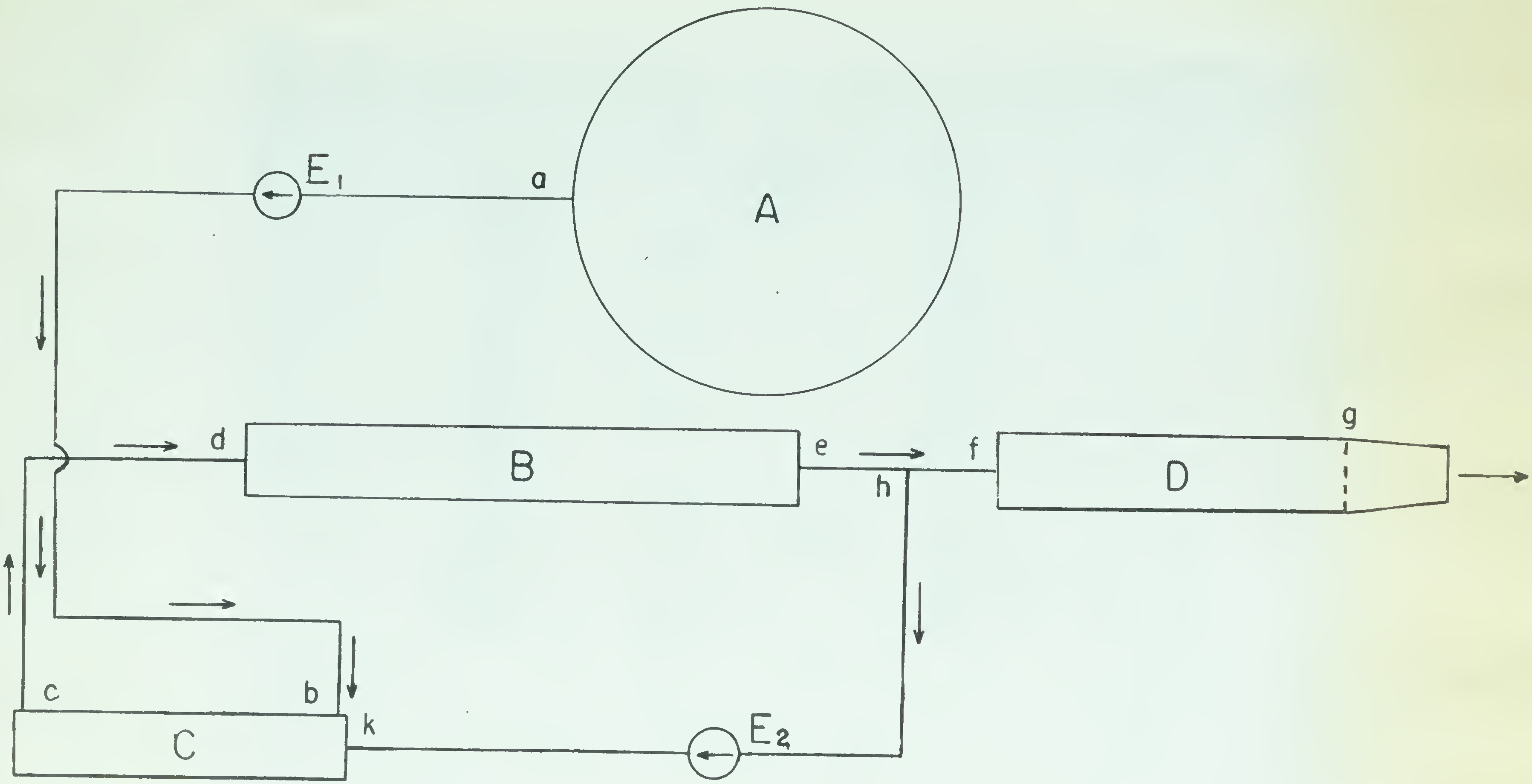

Figure 2. Flow diagram of the laboratory continuous buttermaking machine showing precrystallizing unit. A - mixing tank; B - chiller; C - precrystallizing unit; D - texturator.

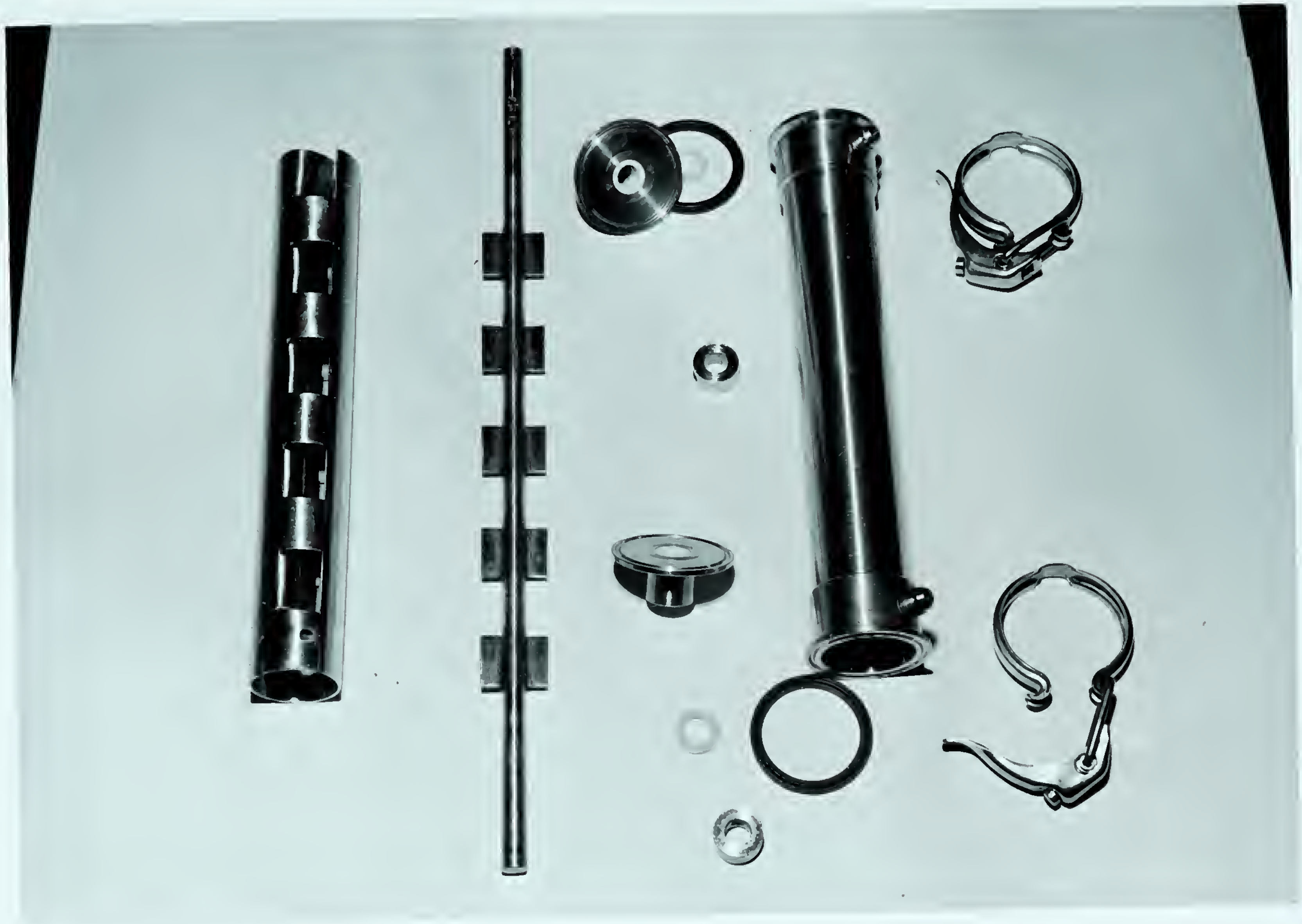

Figure 3. Parts of precrystallizing unit.

directly opposite each other, which rotate inside the stationary section with clearance of approximately 1/8" between rotating and stationary blades. The complete unit was sealed to withstand normal operating pressures by the use of sanitary end plates and o-ring closures fitted around the agitator shaft. The temperature of precrystallization was measured with a thermometer inserted in the line cd (Figure 2) at the outlet of the precrystallizing unit. The precrystallization temperature was controlled by varying the proportion of chilled concentrate that was re-circulated.

Butter Homogenization

A Benhil butter homogenizer, Model Microfix was used in these experiments. This machine consists of a pair of augers turning towards the center of a hopper that propelled the butter towards the homogenizing head. This head is fitted with removable, fixed speed, fine, medium and coarse rotors, having 30, 24 and 16 blades respectively (Figure 4). The augers turned at 8 r. p. m. for minimum and 18 r. p. m. for maximum capacity. The front section of the homogenizer with a rotor in place is shown in Figure 5. Also shown in this figure is the outlet which contains a restrictor or back pressure plate that regulates the flow from the machine and consequently controls the intensity of the homogenizing treatment. In the trials to be reported this control was maintained at the same setting - about half open.

Conventional and continuously made butters were homogenized

Figure 4. Rotors of a Benhil butter homogenizer.
A - fine (30 mesh); B - medium (24 mesh);
C- coarse (16 mesh).

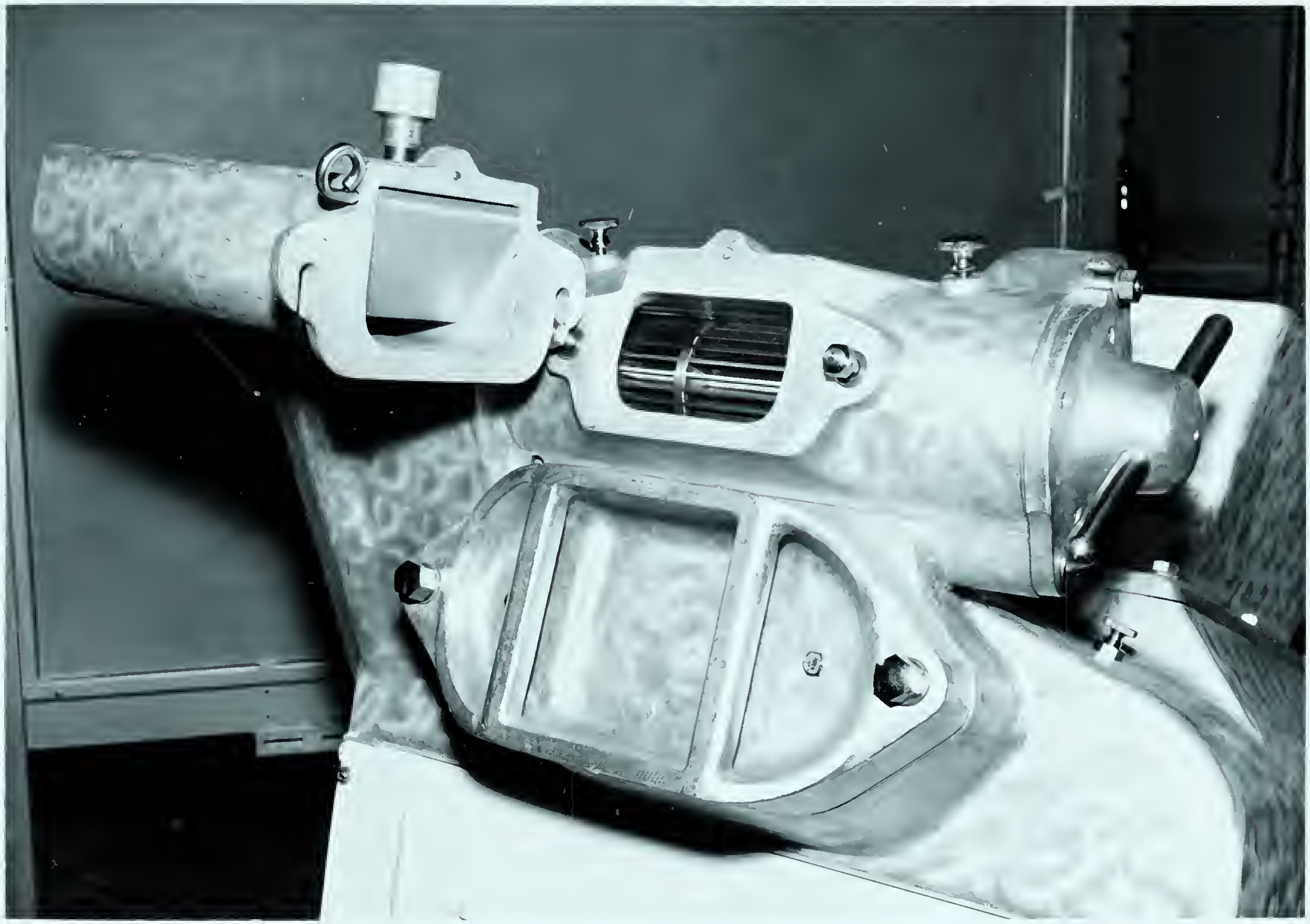

Figure 5. Homogenizing section of Benhil butter homogenizer, showing rotor, rotor housing and outlet with flow restricting plate.

separately in lots of 150 to 300 pounds (in 50 lb packages). Each lot of butter, unless otherwise specified, was stored in a tempering room for at least one week before homogenization, to bring the butter to a relatively constant temperature throughout ($\pm 1^{\circ}F$). The butter was sampled and temperatures recorded before and after homogenizing. Each lot of butter was homogenized with the 16 and/or the 30 mesh rotors at auger speeds of 8 or 18 r. p. m. Samples were taken after the machine attained normal operating conditions.

Hardness

The hardness of butter is usually measured in the range of 12°-17°C. In choosing a measuring temperature the important consideration is that the range of hardness values encountered falls within the range of the particular instrument used. All of the butter except that measured in 7 lb sample boxes was measured at 17°C by the method of Kruisheer & den Herder (1938) as modified by Wood & deMan (1956) to permit tempering the butter samples in a constant temperature bath. Butter in 7 lb grading sample boxes was measured with the unmodified apparatus at 15°C. All hardness measurements reported are the average of two determinations. The modified instrument was calibrated with a balance, and the gauge readings were converted to $kg/4cm^2$ with the aid of a calibration curve.

With the exception of experiments with the laboratory continuous buttermaking machine, which extruded the butter directly into round

frames 2.9 cm in length, made from 2" O. D. stainless steel tubing, the samples of butter were pressed into square frames of 5 cm side and 2 cm height fabricated from 20 gauge stainless steel sheet. The butter samples, unless otherwise stated, were kept in the frames in a cold storage room at 5°C for one week and then tempered in a 17°C water bath for 24 hours before testing. The water bath temperature was maintained thermostatically within ±0.05°C. All hardness measurements were made immediately after removal of samples from the water bath, in a room maintained in the temperature range of 5°-10°C.

The hardness of the butter in 7 lb sample boxes was determined directly at room temperature by the unmodified procedure of Kruisheer and den Herder (1938). Fairly uniform temperatures were obtained by storing the butter for 48 hr. at 5° - 10°C and following this by a further incubation of 48 - 72 hr. at 15°C. Correction of all readings to 15°C was possible through the use of correction curves (Kruisheer & den Herder, 1938). These curves were checked with 32 samples of Alberta butter in the temperature range of 12° - 17°C, and found to be applicable.

Oiling-off

The method used was similar to the one described by Mohr & Baur (1948). Cubes of butter were stored on a pile of filter papers for 48 hr. at 25°C. A special forming device or trier with an internal square cross section of 2.5cm was fabricated from stainless steel sheet (deMan & Wood, 1958c). The plug of butter withdrawn by this

trier (at $5^{o}C$) was pushed out by a closely fitting plunger with an attached graduated stem, and the butter plug was cut off at 2.5 cm length with a stretched wire.

The cube of butter was placed on a pile of ten Whatman No. 1 filter paper circles of 12.5 cm diameter and of known weight. The papers and butter cubes were weighed and stored at $25^{o}C$ for 48 hr. and the cube removed after chilling. During the storage period the filter papers may have absorbed some moisture from the atmosphere. To serve as a control, a pile of ten similar filter papers without a butter cube was stored under the same conditions. After removal from storage, these papers and those containing the absorbed oil were held in a dry atmosphere until the control returned to its original weight. The papers with the absorbed oil were then weighed. Oiling-off is expressed as the weight increase of the filter papers in terms of percentage of the weight of the original butter cube.

Gas Content

A direct method similar to that of deMan & Wood, (1958a) was used in which the gas was liberated from the butter by melting. The escaping gas was collected under water in a graduated tube. The apparatus consisted of hollowed brass frustra of the following specifications: height 44 mm, small inside diameter 22 mm, large inside diameter 28 mm, capacity approximately 20 g; glass funnels (diam. 7 cm) with stems cut to a length of 1 cm; graduated tubes, fabricated from 5 ml measuring pipettes, capacity 2 ml, closed at one end;

rubber connection tubes, length 1 cm.

The funnels with the graduated tubes disconnected, were placed in 1-liter beakers filled with water. After expelling the air by boiling, the beaker and contents were subsequently cooled to room temperature. Without removal from the water, the water-filled tubes were fitted to the stems of the inverted funnels by means of forceps. To avoid excessive foaming, a few drops of sodium hexadecylsulfate were added to the water. The weighed cones were pressed base first into the butter, which had been tempered at 15°C in an incubator. The ends were trimmed and the outside of the cones were carefully wiped clean. The cones of butter were then immersed in the beakers underneath the funnels. The contents of the beakers were heated to 50°C and the collected gas in the graduated tubes read after cooling to room temperature. The volume of gas found was converted to standard pressure (760 mm Hg) and expressed as ml per 100 grams of butter.

Retail Samples of Butter and Margarine

The butterfat and margarine oil were prepared by melting the butter and margarine in beakers at 50° - 60°C followed by centrifuging, filtering the decanted liquid fat through Whatman No. 1 filter paper at room temperature and finally drying the fat under vacuum. The dried fat was stored at -20°C until tested.

The softening point was determined by a modification of the

falling ball method (Barnicoat, 1944) later simplified by Dixon (1959). Liquid fat maintained at approximately 50°C was introduced into a thin walled (5 x 1 cm external diam.) lipped test tube to about 2 cm depth. The test tube containing the fat was cooled in a melting ice bath for 1 hr. and then transferred immediately to an incubator and tempered at 15°C for at least 30 min. Following the tempering period, the test tube and contents were suspended in a well agitated water bath at 15°C; the fat column was maintained at the same level as the thermometer bulb. A 1/8" ball bearing was placed in each tube in the depression formed when the fat cooled. The temperature of the bath was raised at the rate of 0.5°C per min. using a thermo regulated immersion heater. The softening point was recorded as the temperature at which the ball bearing had fallen half-way through the fat column.

Iodine (Wijs) and saponification values were determined by methods of the American Oil Chemists' Society (1952).

The high melting glyceride fraction of the fat was determined by a modification of a solvent crystallization method (Täufel _et al._, 1958). Ten gram samples of dried fat at 40°C were weighed into 125 ml Erlenmeyer flasks and dissolved completely in 25 ml of ether to which 10 ml of absolute ethanol were then added and the flasks swirled to ensure complete mixing. The flasks were stoppered tightly and stored in a water bath thermostatically controlled at 15 ±0.01°C for 16 - 20 hr. The clear solution and high melting glyceride crystals were transferred quantitatively to a weighed Gooch type crucible with fritted disc

using a solution - 3 ether/2 absolute ethanol - maintained near -20°C. The crucibles and contents were held under vacuum in a desiccator at room temperature until all traces of ether and alcohol had been removed. The crucibles were weighed and the values reported as percent high melting glycerides.

Polarized Light Microscopy

As it was desirable to obtain information not only on the size and shape of fat crystals but also on their approximate quantity, a technique developed by Herb, et al.(1956) was used which made it possible to examine layers of butter of definite and known thickness. As the butter at the temperature of examination (5 - 10°C) was too hard to be easily spread on a glass slide, a dilution method was necessary. This gave the added advantage of more detailed pictures.

A definite quantity of butter was weighed on a slide. The weight of the sample was calculated so that it would form a layer 10 μ thick when spread evenly over the area occupied by a round cover glass of 22 mm diameter. An equal quantity of light mineral oil was then weighed on to the same slide and the two substances mixed carefully and thoroughly with a small spatula. Because some of the specimen adhered to the spatula, the slide was weighed again and the weight of specimen reduced to half by removing the excess with the spatula. When covered with the round cover glass and spread evenly with slight pressure to fill exactly the area under the cover glass, this quantity of specimen yielded a layer 10 μ thick, representing half butter and half mineral

oil.

The microscope used in this study was a Zeiss-Winkel standard polarizing microscope which has the illumination built into the base. The photomicrographs were made with the Zeiss-Winkel attachment camera and focusing eyepiece. The magnification on all photomicrographs is 1,875 x.

RESULTS

Hardness Variability of Bulk Butter in Seven Pound Grading Samples

For a period of one year, samples of butter in 7 lb grading boxes were collected for hardness measurements in order to obtain further information on the variability of hardness in different creameries, between creameries and seasonally on unprinted bulk butter at the time of grading. Most of the information previously available was based on butter obtained at Edmonton creameries. The butter was all manufactured by the conventional (churn) method and represented the production of five creameries in the Edmonton area. The hardness values for three samples each month for a year from the five creameries, with average monthly values are shown in Figure 6. The average monthly hardness values are also shown in Table 1. The values reported show that hardness of the butter samples varied considerably within each month and for each creamery. The mean hardness values for the one year period and the amount of hardness variation for the five creameries are reported in Table 2. These values show that, except for the butter of creamery A, the greater mean hardness is paralleled by a correspondingly greater hardness variation. It is evident from Figure6 that the hardness of butter from creameries B and C does vary considerably more than that from creameries A, D and E, and this is substantiated by the calculated variability in Table 2. By Duncan's Multiple Range Test butter from creamery B, which was

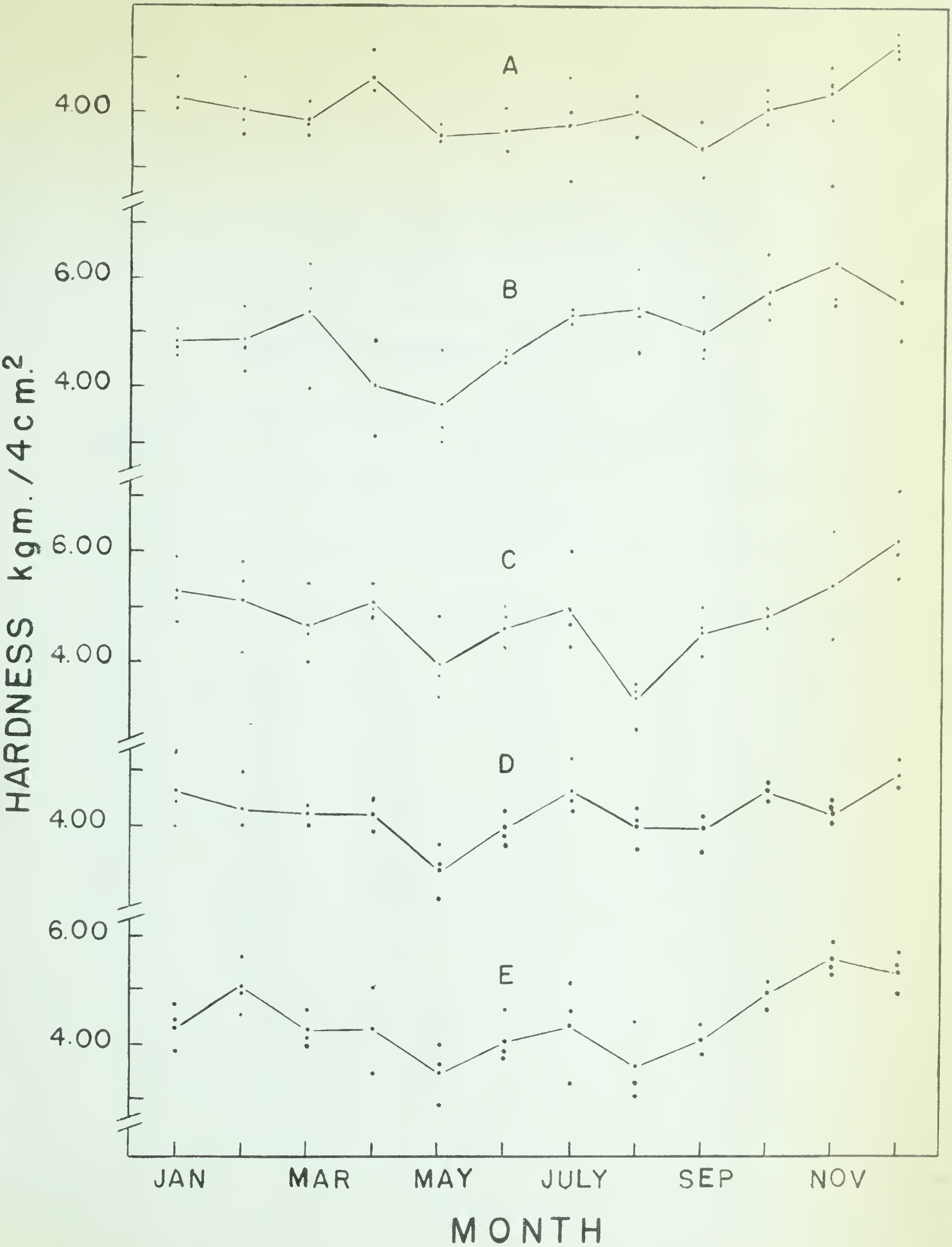

Figure 6. Seasonal variation in hardness of bulk conventional butter in seven pound grading samples as measured by unmodified apparatus. (Kruisheer & den Herder, 1938) at 15°C.

Table 1. A comparison of the average hardness of bulk conventional butter in seven pound grading samples as measured by unmodified apparatus (Kruisheer & denHerder, 1938) at 15°C

Month	Hardness (Kg/4 cm^2)				
	Creamery				
	A	B	C	D	E
Jan.	4.38	4.81	5.30	4.64	4.37
Feb.	4.06	4.87	5.19	4.34	5.05
Mar.	3.88	5.40	4.69	4.20	4.27
Apr.	4.69	3.06	5.12	4.23	4.30
May	3.63	3.70	4.02	3.28	3.56
June	3.70	4.66	4.76	3.99	4.13
July	3.81	5.37	5.05	4.69	4.41
Aug.	4.09	5.44	3.39	4.02	3.66
Sept.	3.39	5.05	4.66	4.02	4.16
Oct.	4.16	5.79	4.97	4.76	5.05
Nov.	4.45	6.36	5.51	4.37	5.61
Dec.	5.28	5.66	6.30	5.03	5.42
Ave.	4.13	5.10	4.91	4.30	4.50

Table 2. A comparison of the mean hardness and variability of hardness of bulk conventional butter in seven pound grading samples as measured by unmodified apparatus (Kruisheer & den Herder, 1938) at 15°C

Creamery	Hardness ($Kg/4\ cm^2$)*	Variability of hardness**
B	5.10	±0.95
C	4.91	±0.90
E	4.50	±0.77
D	4.30	±0.56
A	4.13	±0.64

* mean hardness of 36 samples of butter from each creamery over the one year period.

** Standard deviation.

manufactured from vacreated cream, was found to be harder (significant at the 1% level) than butter from creameries A and D and harder (significant at the 5% level) than butter from creamery E. The butter from C the most northerly creamery was harder (significant at the 1% level) than butter from creamery A and harder (significant at the 5% level) than butter from creamery D but was not significantly different in hardness from butter of creamery E. Minimum average hardness values are noted in May for creameries B, D and E, in August for creamery C and September for creamery A. Maximum average hardness values are noted in November for creameries B and E and December for creameries A, C and D.

Retail Samples of Butter and Margarine

Investigation of 1 lb retail prints of butter and margarine were carried out to obtain information on the comparative hardness of these two products, particularly margarine, for which only meagre data are available. The trials were conducted, quarterly for a period of one year and each trial included samples of four butters, one continuous, and five margarines. The season of manufacture of all samples was unknown. Besides hardness tests (Table 3) determinations were made of softening points, oiling-off percentages, iodine values, saponification values and high melting glyceride percentages; these are presented in tables 4, 5, 6, 7 and 8 respectively. From these tables some general observations may be made. The average hardness of margarine samples was consistently higher than that of the butters,

Table 3. A comparison of the hardness of retail prints of butter and margarine

Brand	Hardness ($Kg/4\ cm^2$)					
	May	Aug.	Nov.	Feb.	May	Ave.
			Butter			
A	1.40	1.30	2.59	1.87	1.71	1.77
B	1.52	1.11	1.32	2.21	2.31	1.69
C	1.34	1.52	2.54	1.41	1.82	1.73
D	3.65	3.94	5.32	4.52	3.72	4.23
			Margarine			
E	2.70	2.81	4.42	5.32	2.64	3.58
F	2.32	3.30	2.56	3.41	2.36	2.79
G	1.80	1.20	2.54	2.44	1.98	1.99
H	1.76	2.47	3.77	1.68	2.04	2.34
I	1.96	1.44	2.14	2.19	1.64	1.87

Table 4. A comparison of the softening points of butterfat and margarine oil from retail prints of butter and margarine

Brand	Softening point (°C)					
	May	Aug.	Nov.	Feb.	May	Ave,
			Butter			
A	33.8	31.6	32.6	32.1	33.5	32.7
B	33.3	31.5	31.9	32.2	32.1	32.2
C	33.3	33.5	33.4	32.9	32.7	33.6
D	34.3	33.6	33.4	33.0	33.2	33.5
			Margarine			
E	33.9	32.6	32.8	32.9	33.1	33.1
F	33.0	33.2	33.4	33.7	33.9	33.4
G	34.0	34.0	34.6	34.7	35.8	34.6
H	34.3	32.8	35.2	33.2	33.1	33.7
I	33.8	33.2	33.5	33.8	34.0	33.7

Table 5. A comparison of the oiling-off percentages of retail prints of butter and margarine

Brand	Oiling-off (%)					
	May	Aug.	Nov.	Feb.	May	Ave.
			Butter			
A	10.5	10.4	7.7	9.8	8.9	9.5
B	11.4	11.1	10.0	8.6	9.8	10.2
C	9.6	8.4	6.0	9.1	11.0	8.8
D	12.6	10.8	8.0	9.7	11.9	10.6
			Margarine			
E	7.6	7.8	3.6	3.9	6.4	5.9
F	6.4	5.0	3.8	4.0	6.2	5.1
G	6.4	7.1	4.4	5.7	5.7	5.9
H	5.1	4.7	2.6	12.0	8.9	6.7
I	-	6.8	5.0	7.3	6.0	6.3

Table 6. A comparison of the iodine values of butterfat and margarine oil from retail prints of butter and margarine

Brand	Iodine value				
	Aug.	Nov.	Feb.	May.	Ave.
			Butter		
A	39.9	36.8	39.6	38.6	38.7
B	40.1	39.9	37.2	36.7	38.5
C	39.6	35.4	39.1	35.8	37.5
D	38.1	37.2	37.1	38.2	37.6
			Margarine		
E	91.0	85.4	83.9	90.0	87.6
F	78.1	77.4	76.0	78.2	77.4
G	78.0	77.3	77.3	77.2	77.4
H	75.8	76.4	81.0	80.9	78.5
I	78.0	75.6	79.0	79.4	78.0

Table 7. A comparison of the saponification values of butterfat and margarine oil from retail prints of butter and margarine

Brand	Saponification value				
	Aug.	Nov.	Feb.	May	Ave.
			<u>Butter</u>		
A	225.6	227.0	231.1	227.9	227.9
B	226.0	231.0	228.0	229.0	228.5
C	225.5	226.6	227.7	227.4	226.8
D	227.7	225.4	227.4	223.5	226.0
			<u>Margarine</u>		
E	195.3	192.5	192.4	190.1	192.6
F	191.6	192.4	194.9	193.0	193.0
G	190.8	192.6	190.1	189.7	190.8
H	188.9	194.6	191.3	192.0	191.7
I	193.0	193.0	194.4	192.9	193.3

Table 8. A comparison of the percentage and melting point of high melting glycerides of butterfat and margarine oil from retail prints of butter and margarine

Brand	High melting glyceride (%)					H.M.G. (Melting point ^{o}C)			
	Aug.	Nov.	Feb.	May	Ave.	Aug.	Nov.	Feb.	May
					Butter				
A	2.9	2.8	2.1	3.4	2.8	56.7	56.0	56.5	57.2
B	2.3	1.0	3.0	2.3	2.2	57.0	56.5	57.5	57.4
C	2.2	2.8	1.8	2.2	2.2	56.6	56.5	56.7	57.5
D	2.0	2.4	2.2	2.5	2.3	56.5	55.6	56.7	57.3
					Margarine				
E	0.8	-	-	-	-	62.8	-	-	-
F	*	0.5	0.7	1.2	-	-	54.9	54.9	57.3
G	0.3	-	-	-	-	56.4	-	-	-
H	0.6	3.1	1.3	1.3	-	57.7	55.7	58.4	58.7
I	0.4	*	0.7	0.9	-	54.2	-	58.0	58.0

* Trace

with the exception of the continuously made butter D. Softening points of both butterfat and oil from margarine were similar with a tendency for the margarine values to be higher. The average oiling-off percentages for the butters were consistently higher than those for the margarine. The vegetable oils from margarine samples had consistently much higher iodine values and consistently much lower saponification values than the butterfats. The iodine and saponification values were determined in the event that differences in physical properties of butter and margarine might be explained on the basis of differences in unsaturation and/or chain length of fatty acids, but this was not the case. The average high melting glyceride percentage of the butterfats was surprisingly uniform and consistently higher than that of the vegetable oils from the margarine. A very interesting similarity in the melting points for the high melting glyceride fractions obtained for both products was noted. Besides small variations between brands and between butter and margarine samples as a whole, an apparent variation occurs between samples within a brand.

Although butter D was consistently harder than all other butters the averages of all other values for this butter are very similar to values obtained for the other three brands. Similarly margarine E, which has an average hardness value exceeding all of the other margarine brands only differed from the other brands by virtue of a consistently higher iodine value.

The characteristic crystal structures of a continuously made and

a conventional butter sample studied in these trials are shown in Figures 7 and 8. It is evident from these polarized light photomicrographs that the continuous type butter contains larger fat crystals than the conventional butter. In addition to the very small crystals, the conventional butter contained a large number of fat globules.

Polarized light photomicrographs from a hard and soft sample of margarine are shown in Figure 9 and 10 respectively. The hard margarine obviously contained larger crystals and more crystalline fat than was present in the soft margarine.

Precrystallization

Comparisons of continuous (using a cooling coil) and batch methods of precrystallization of the same butter concentrate are shown in Table 9. All of these results were obtained with the laboratory continuous buttermaking equipment. From the results of these representative trials, it is evident that precrystallization did not take place in the continuous method. With the batch procedure, on the other hand the hardness of the butter was effectively reduced, 32.2 and 45.6%, in these trials. The reduction in hardness of batch precrystallization was, however, accompanied by oiling-off percentages of 26.6 and 37.9. In spite of this large oiling-off tendency, the texture of the butter was acceptable, being free from any coarse or grainy texture.

Figure 7. Polarized light photomicrograph of the crystal structure of retail continuously made butter.

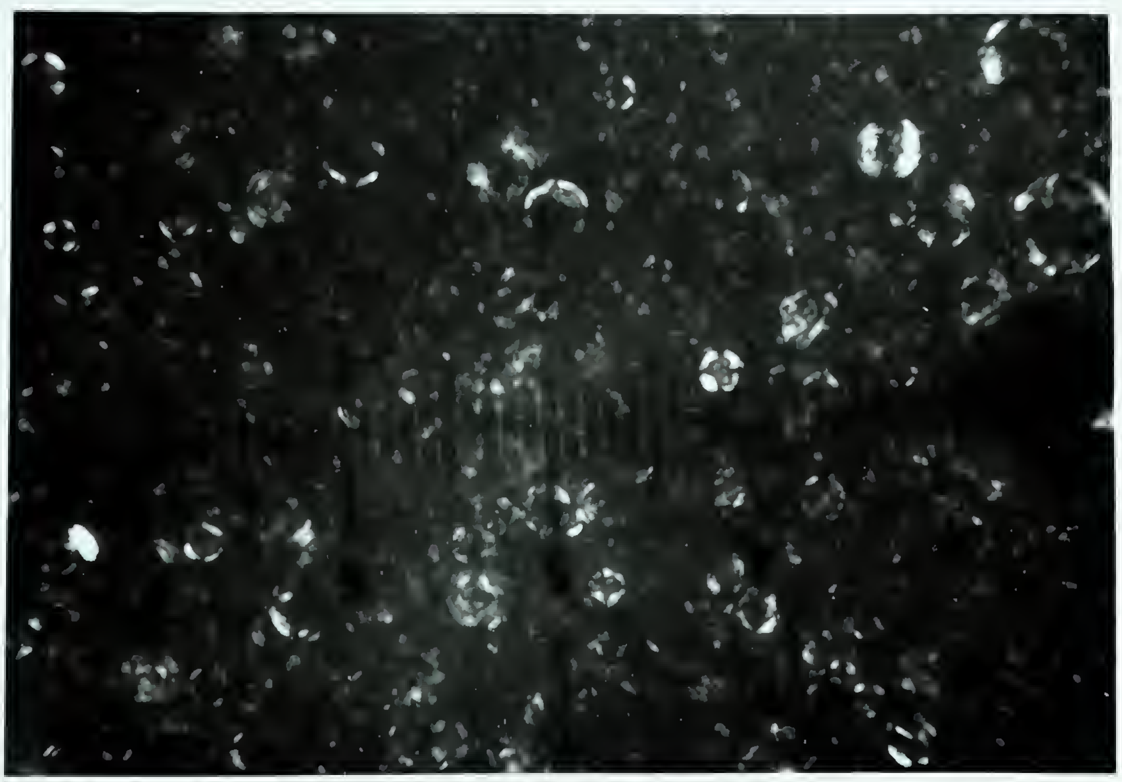

Figure 8. Polarized light photomicrograph of the crystal structure of retail conventional butter.

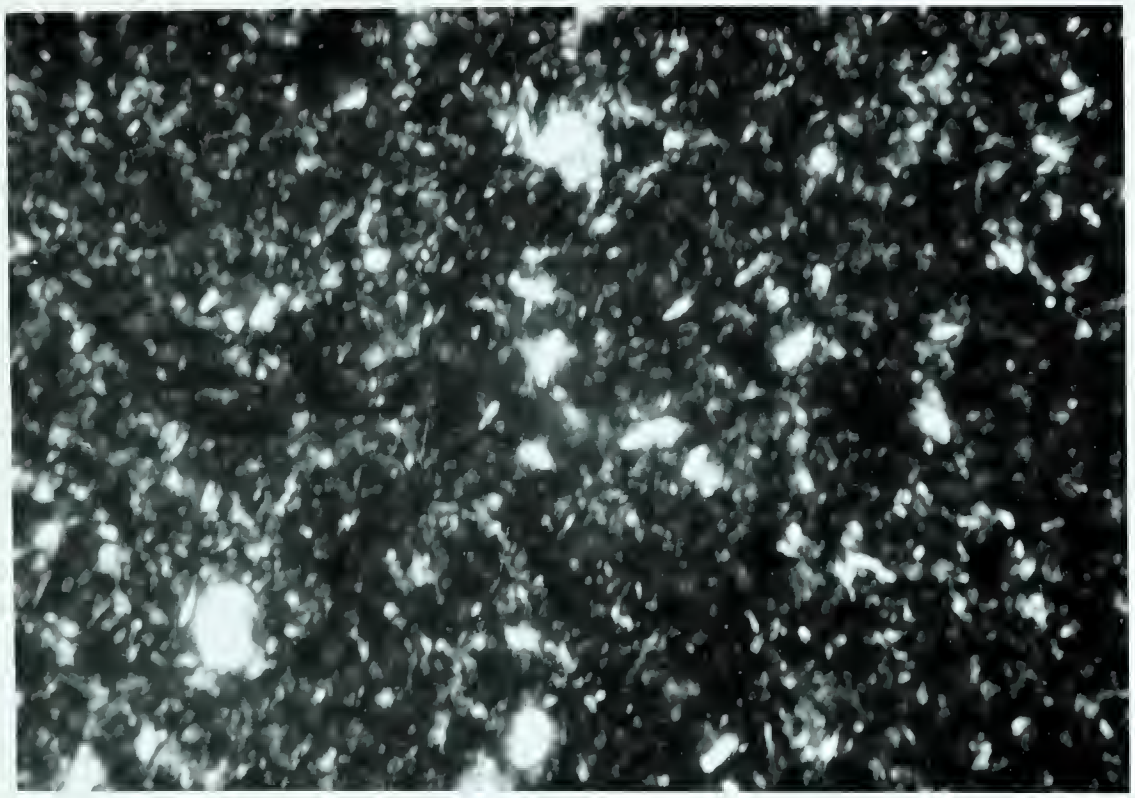

Figure 9. Polarized light photomicrograph of the crystal structure of a hard margarine.

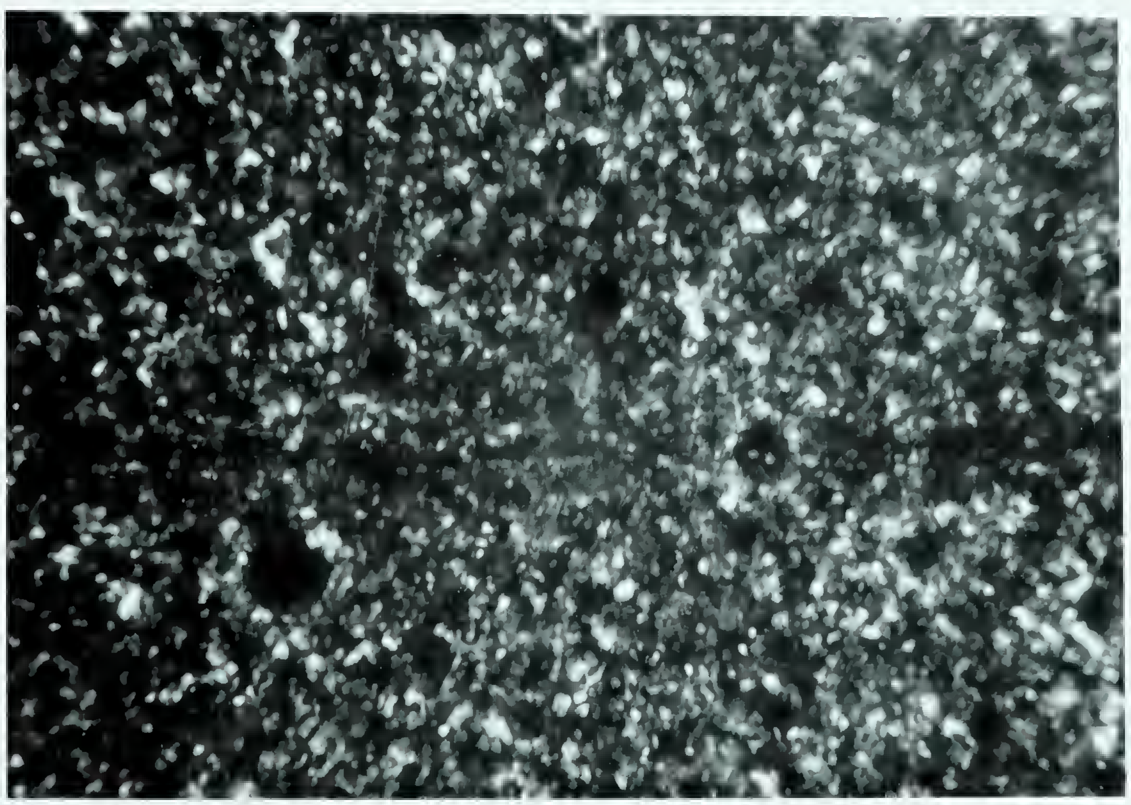

Figure 10. Polarized light photomicrograph of the crystal structure of a soft margarine.

Table 9. The effect of continuous (using a cooling coil) and batch precrystallization of the same butterfat concentrate on hardness and oiling-off properties of butter made with the laboratory continuous buttermaking machine

Trial No.	Precrystallization		Hardness		Oiling-off
	Method	Temp. (^{o}F)	(Kg/4 cm^2)	Reduction (%)*	(%)
1	control**	-	2.83		13.9
	continuous	(95	2.83		12.2
		(85	2.88		14.5
		(75	2.83		17.3
	batch	78	1.92	32.2	26.6
2	control	-	3.16		13.6
	continuous	(95	3.07		-
		(85	3.11		-
		(78	3.01		-
		(65	2.85		-
	batch	83	1.72	45.6	37.9

* reduction below the hardness values obtained for the non-precrystallized controls

** non-precrystallized butterfat concentrate

Polarized light photomicrographs representative of butter from the continuously precrystallized concentrate are shown in Figures 11, 12, 13 and 14. As might be anticipated from the lack of reduction in the hardness of the butter, there is no apparent change in the size or quantity of crystalline fat as a consequence of the continuous precrystallization. From Figure 15, however, it is evident that the size of the butterfat crystals has been markedly increased by the batch procedure.

Further trials with the batch precrystallization procedure with laboratory continuous buttermaking machine are shown in Table 10. The results shown in this table are similar to those reported in Table 9. The butters with the greatest reduction in hardness, trials 1 and 3, were made from concentrate precrystallized at 80° and 79°F respectively. This reduction in hardness was accompanied by the highest oiling-off percentage. These changes in the physical properties of the butter undoubtedly arise from a change in the crystal structure and size as seen in Figure 15.

Some batch precrystallization trials conducted with the commercial continuous buttermaking equipment are shown in Table 11. In all the trials the hardness of the precrystallized butter was effectively reduced below that of the non-precrystallized controls. These results show a hardness reduction ranging from 19.4% for trial 1 to 58.3% for trial 2. The most effective precrystallization temperature appears to be somewhat below 89°F. The average reduction

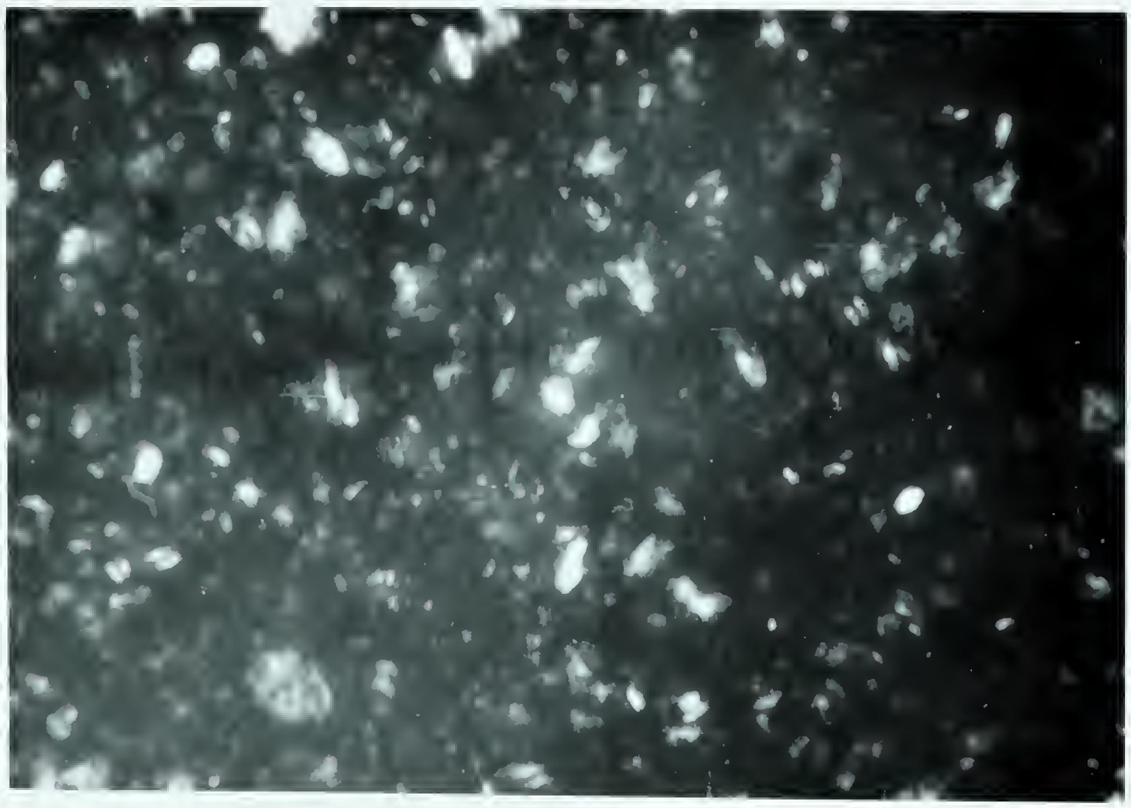

Figure 11. Polarized light photomicrograph of the crystal structure of butter from non-precrystallized concentrate (laboratory).

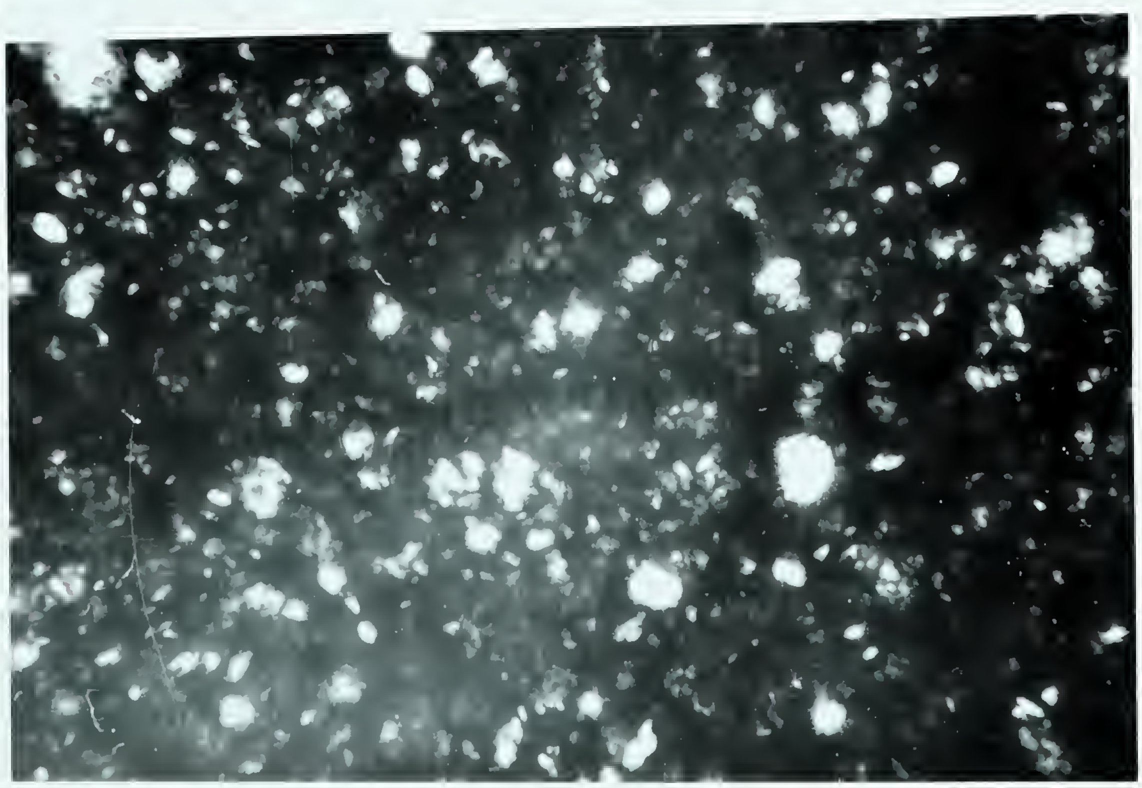

Figure 12. Polarized light photomicrograph of the crystal structure of butter from concentrate continuously precrystallized (cooling coil) at 95°F.

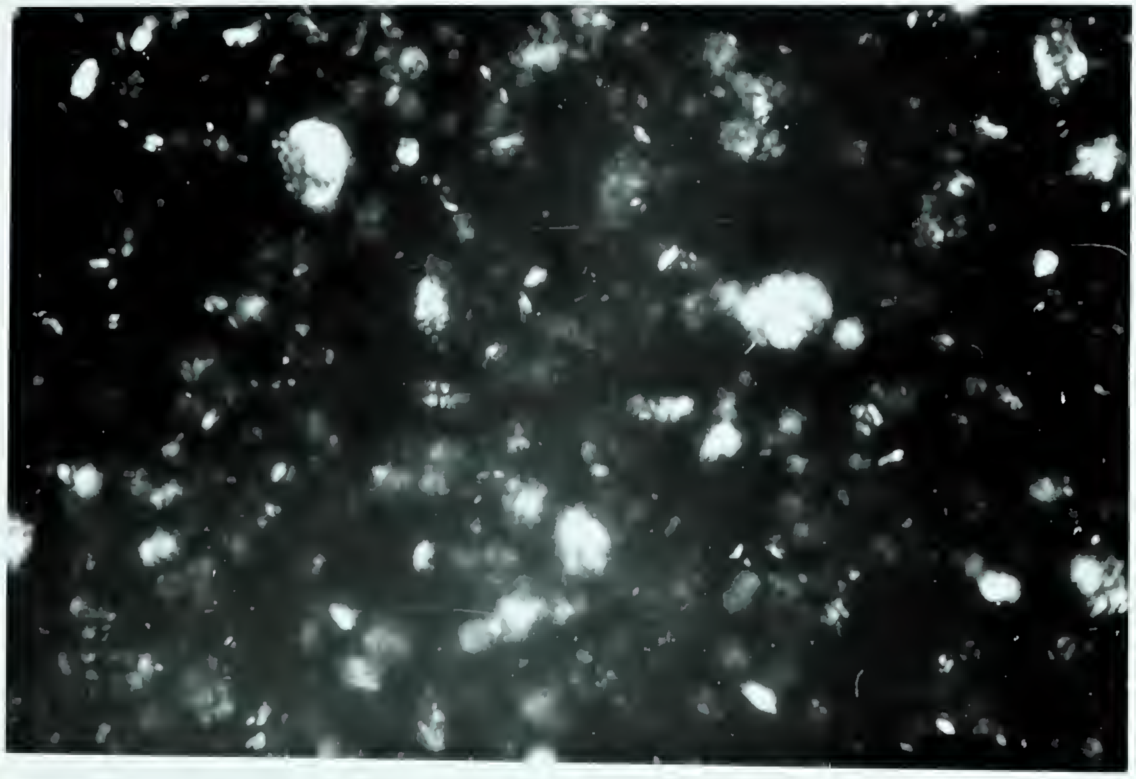

Figure 13. Polarized light photomicrograph of the crystal structure of butter from concentrate continuously precrystallized (cooling coil) at 85°F.

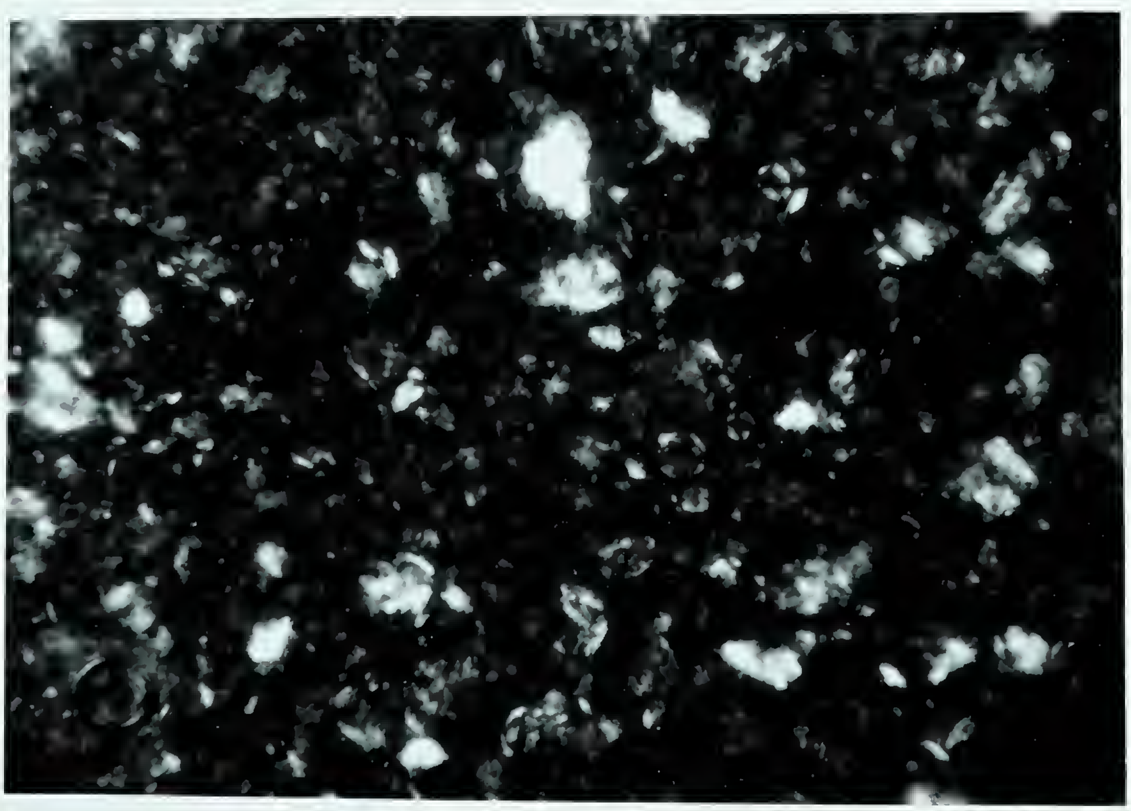

Figure 14. Polarized light photomicrograph of the crystal structure of butter from concentrate continuously precrystallized (cooling coil) at 75°F.

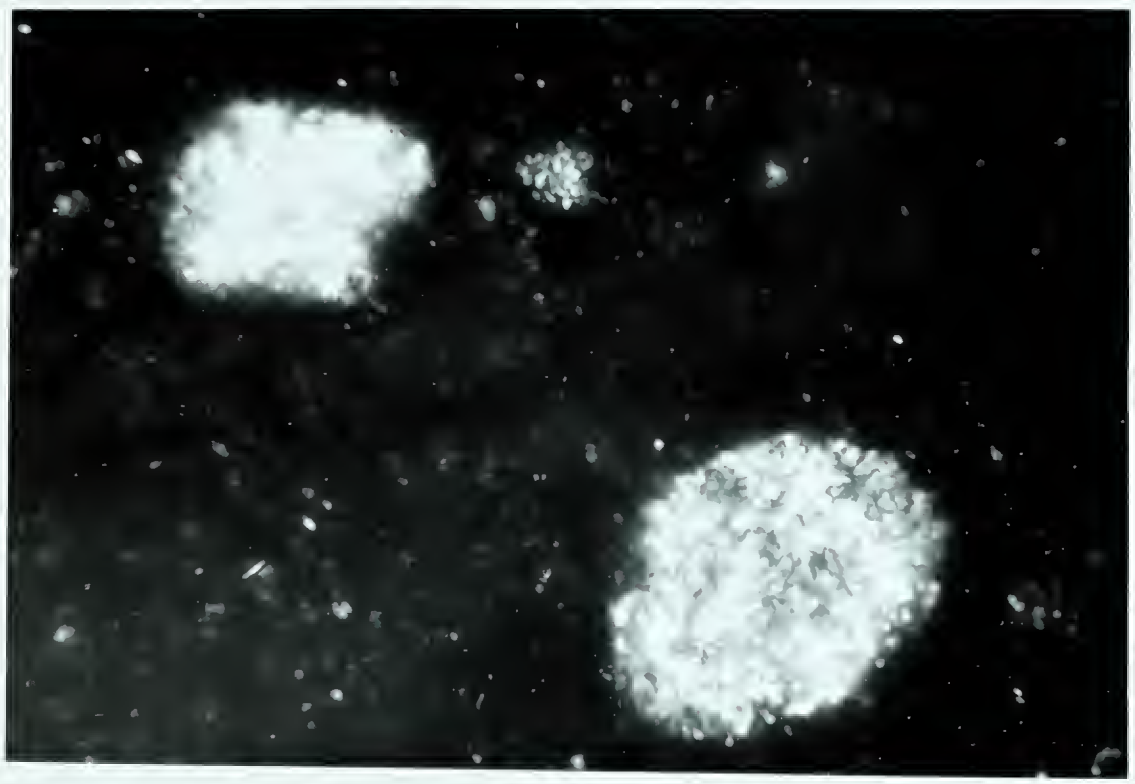

Figure 15. Polarized light photomicrograph of the crystal structure of butter from concentrate batch precrystallized (laboratory) at 78°F.

Table 10. The effect of batch precrystallization of the butterfat concentrate on hardness and oiling-off of butter made with the laboratory continuous buttermaking machine

Trial No.	Precrystallization	Hardness		Oiling-off
	Temp. (^oF)	($Kg/4\ cm^2$)	Reduction (%)*	(%)
1	control**	3.37		15.9
	85	2.44	27.6	30.6
	80	1.52	54.9	36.8
2	control	3.00		12.2
	90	1.96	34.7	20.0
3	control	2.72		15.5
	79	1.38	49.3	31.4
4	control	2.13		15.0
	90	2.10	1.4	15.6
5	control	3.00		12.4
	86	1.98	34.0	21.1

* reduction below the hardness values obtained on the non-precrystallized controls

** non-precrystallized butterfat concentrate

Table 11. The effect of batch precrystallization of the butterfat concentrate on hardness and oiling-off properties of butter manufactured with the commercial continuous buttermaking equipment

Trial No.	Precrystallization Temp. (°F)	Hardness ($Kg/4\ cm^2$)	Hardness Reduction (%)*	Oiling-off (%)
1	control**	2.88		13.4
	89	2.32	19.4	18.0
2	control	3.21		13.9
	81	1.34	58.3	43.0
3	control	3.24		12.5
	82	1.67	48.5	37.2
4	control	3.67		12.8
	84	1.79	51.2	31.7
5	control	2.76		12.1
	84	1.73	37.3	28.8
6	control	4.02		12.5
	84	2.01	50.0	28.6
7	control	3.45		12.8
	81	2.11	38.8	32.8
8	control	4.43		8.4
	80	1.92	56.7	36.6
Ave.	control	3.46		12.3
	precrystallized	1.86	46.2	32.1

* reduction below the hardness values obtained on the non-precrystallized controls

** non-precrystallized butterfat concentrate

for all trials was 46.2%. The hardness reduction of the butter was accompanied by a parallel increase in the oiling-off percentage similar in magnitude to that obtained for batch precrystallization with the laboratory equipment. The average oiling-off percentage was increased from 12.3% the average of the non-precrystallized controls to 32.1%.

Polarized light photomicrographs of butter made from non-precrystallized and precrystallized (89°F) concentrate are shown in Figures 16 and 17 respectively. In this trial, No. 1 in Table 11, the reduction in hardness was the smallest obtained and there is no discernable change in the size or quantity of crystalline butterfat. In trial No. 2, on the other hand, the photomicrographs, Figures 18 and 19 show the increase in crystal size that occurred as a consequence of precrystallization. This butter was made from a butter concentrate precrystallized at 81°F that had a reduction in hardness of 58.3%, trial No. 2 Table 11.

The results obtained in a series of experiments with a continuous precrystallizing unit are shown in Table 12. These data show that this precrystallization method was very effective in reducing the hardness of butter. With the exception of the results obtained in trial No. 1 these data show that the most effective precrystallizing temperature range is approximately 70 - 75°F. Precrystallizing temperatures above and below this range were less effective.

The oiling-off percentages are also shown in Table 12. It is

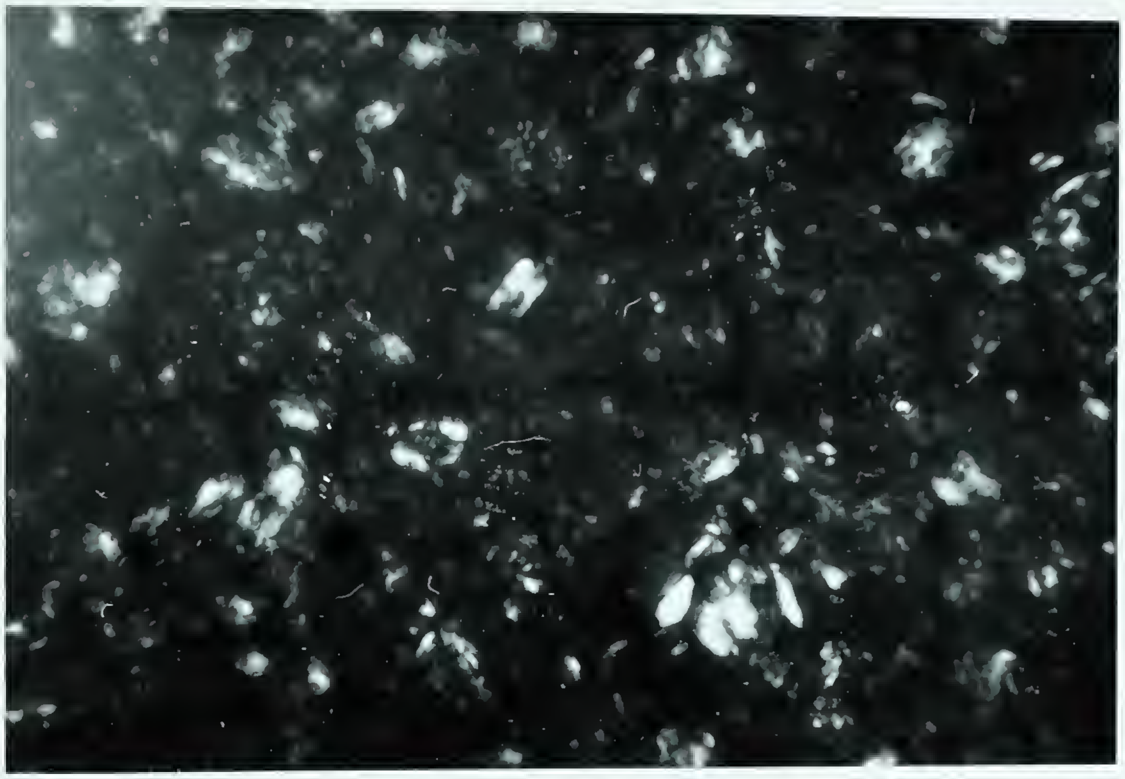

Figure 16. Polarized light photomicrograph of the crystal structure of butter from non-precrystallized concentrate (commercial).

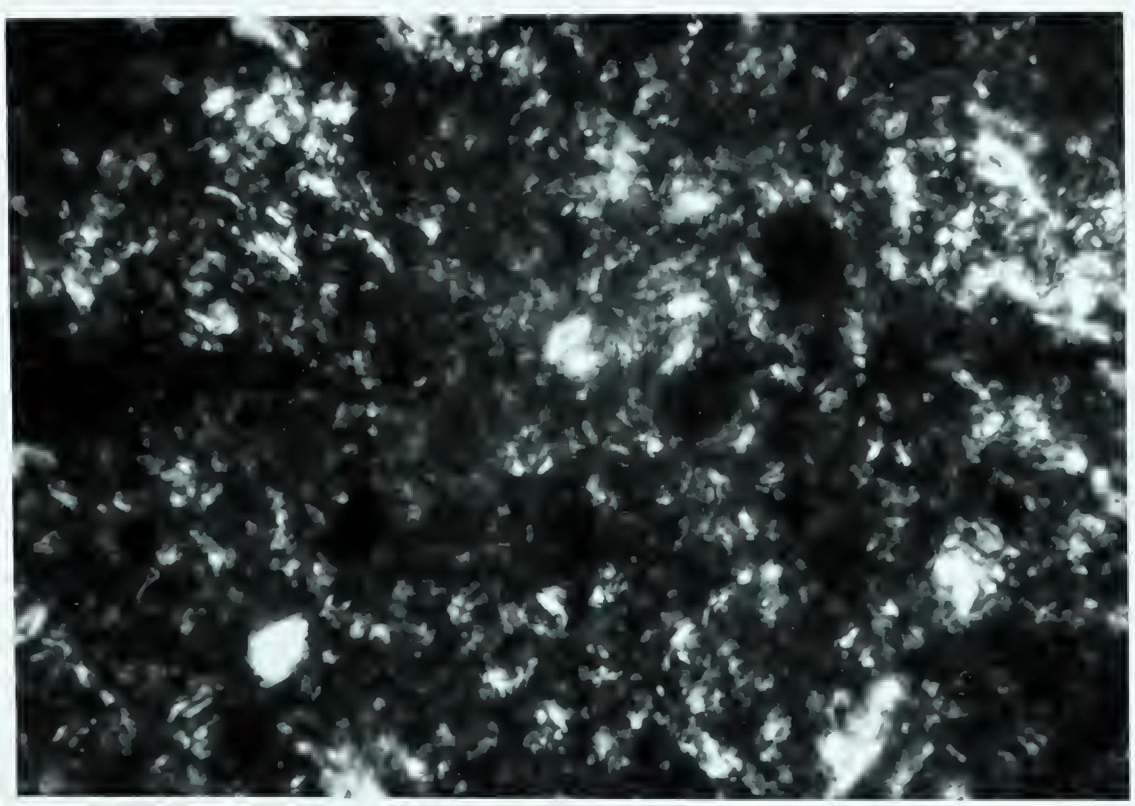

Figure 17. Polarized light photomicrograph of the crystal structure of butter from concentrate batch precrystallized (commercial) at 89°F.

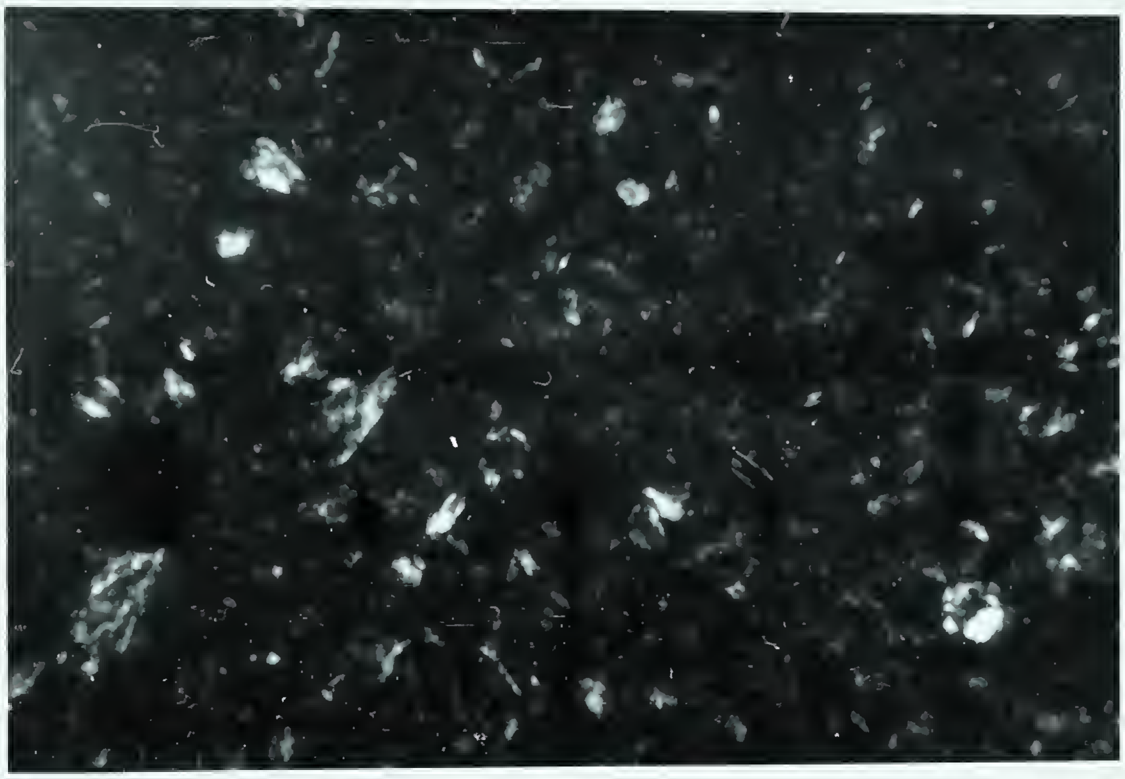

Figure 18. Polarized light photomicrograph of the crystal structure of butter from non-precrystallized concentrate (commercial).

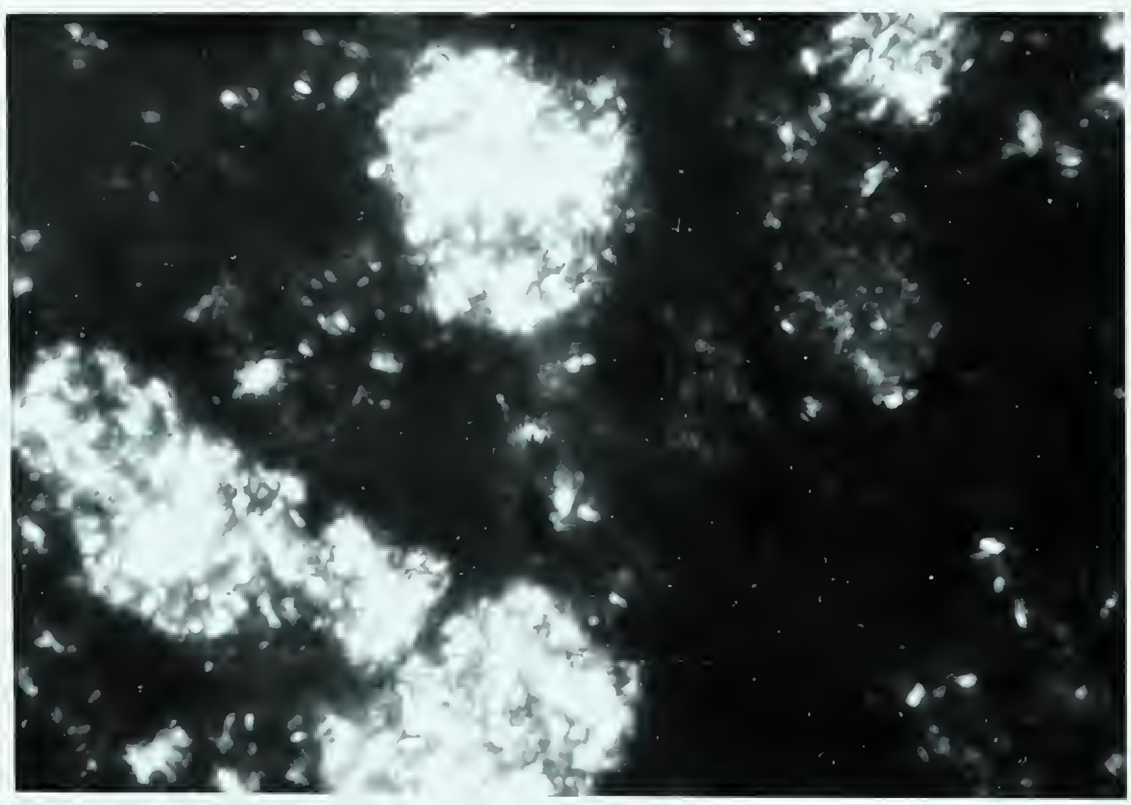

Figure 19. Polarized light photomicrograph of the crystal structure of butter from concentrate batch precrystallized (commercial) at 81^{o}F.

Table 12. The effect of continuous precrystallization of butterfat concentrate using a precrystallizing unit, on the hardness and oiling-off properties of butter

Trial No.	Precrystallization Temp. (^{o}F)	Hardness (Kg/4 cm^2)	Hardness Reduction (%)*	Oiling-off (%)
1	control**	2.19		15.6
	60	2.10	49.8	13.2
2	control	3.58		12.7
	82	2.38	33.5	19.8
	71	1.86	48.0	14.7
	60	1.89	47.2	12.2
3	control	3.84		7.4
	74	2.08	45.8	8.2
	62	2.42	37.0	7.6
4	control	3.50		10.7
	71	1.83	47.7	10.9
	61	1.94	44.6	8.0
5	control	4.13		7.8
	74	2.61	36.8	9.6
	65	2.66	35.6	7.6
6	control	2.72		15.5
	70	1.58	41.9	12.4
	59	1.95	28.3	12.6
7	control	2.13		15.0
	82	1.57	26.3	19.4
	70	1.21	43.2	15.0
	60	1.38	35.2	11.5
8	control	3.00		12.4
	78	1.86	38.0	18.0
	70	1.46	51.3	15.6
	60	1.74	42.0	11.4

* reduction below the hardness values obtained on the non-precrystallized controls

** non-precrystallized butterfat concentrate

evident from these results that with the exception of trials 2, 7 and 8, in which the precrystallization temperature was above the range for maximum reduction in hardness, over 75°F, the oiling-off tendency was normal for this type of butter (deMan and Wood, 1958c).

Polarized light photomicrographs of the butter made with the precrystallization unit are shown in Figures 20, 21, 22 and 23. These photomicrographs indicate that precrystallization at 80°F and 70°F favours an increase in the size of the butterfat crystals while precrystallization at 60°F produced a lower percentage total crystalline butterfat. The decrease in hardness of the butter made from butter concentrate precrystallized in the temperature range of 70 - 75°F can apparently be attributed in part to an increase in size of crystals, and this may in some instances, as the temperature approached 80°F, increase the oiling-off percentages. Figure 23 shows a decrease in crystalline butterfat.

The Homogenization of Butter

The results obtained by homogenizing representative churnings of conventional and continuously made butters over the period of one year are shown in Tables 13 and 14 respectively. The data in Table 13 show the reduction in hardness for conventional butter ranged from 32.6 to 66.9% with an average reduction for 40 churnings of 50.8%. The reduction for continuously made butter (Table 14) was less with a range of 12.1 to 56.3% and an average reduction for

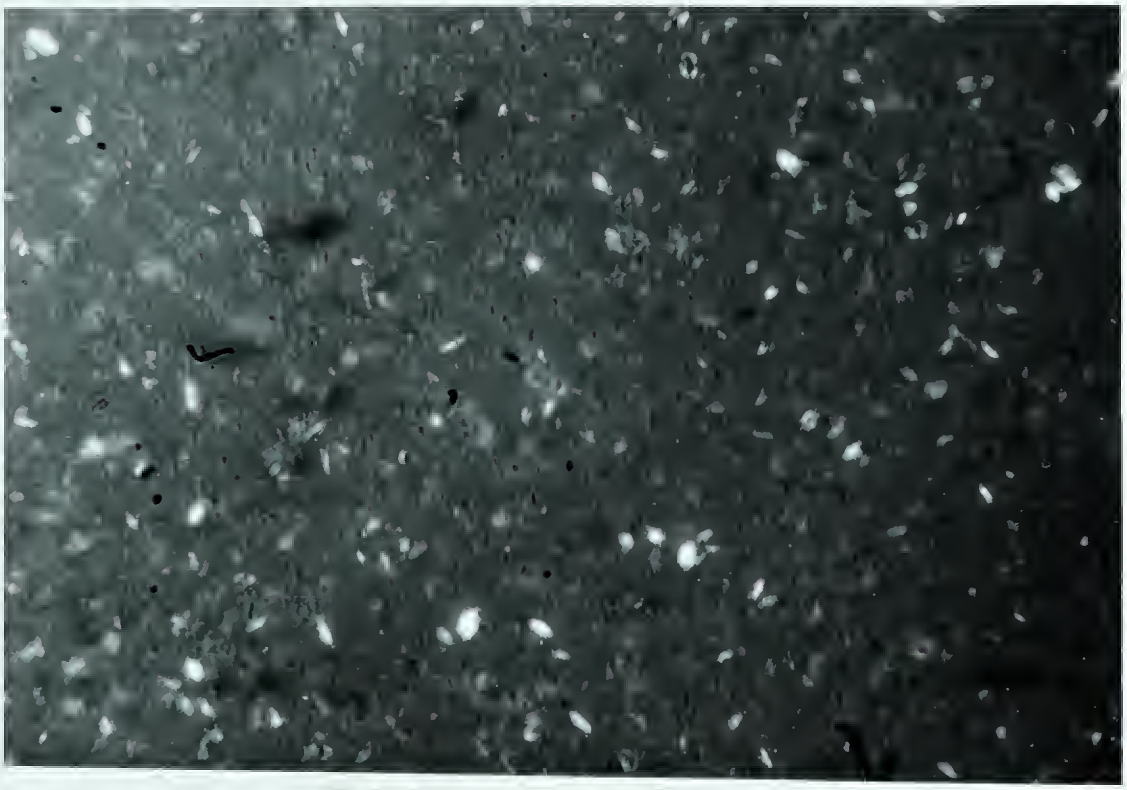

Figure 20. Polarized light photomicrograph of the crystal structure of butter from non-precrystallized concentrate (laboratory).

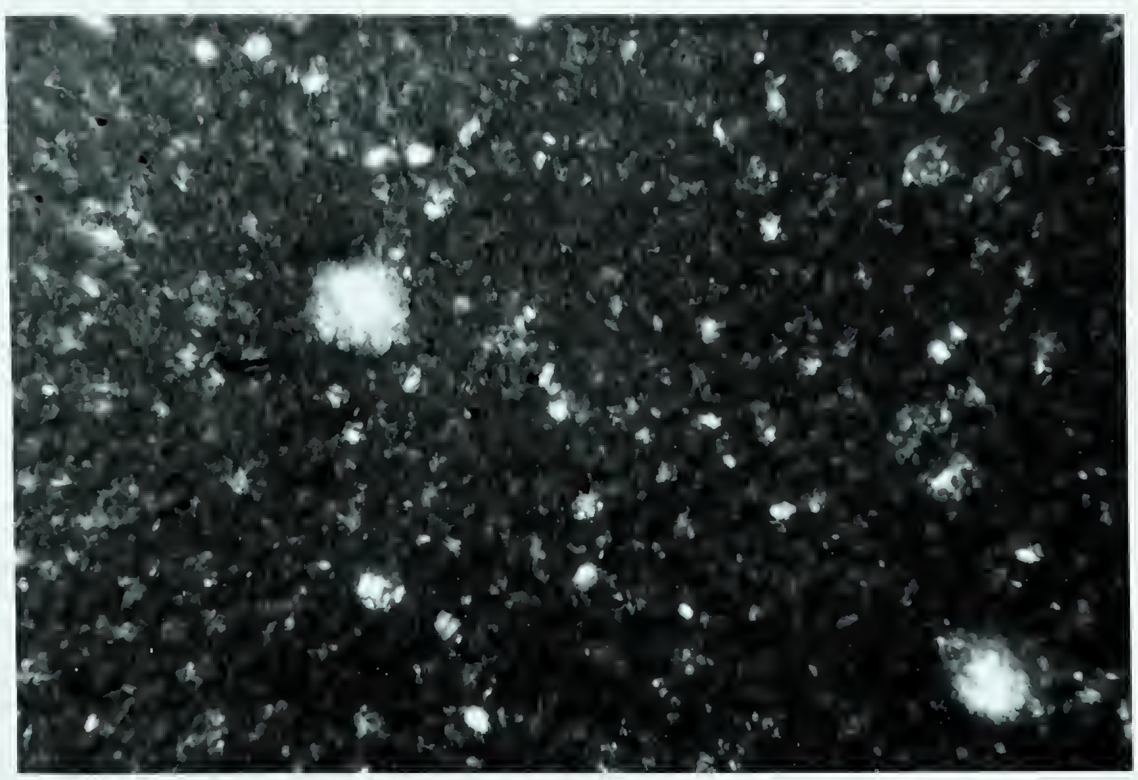

Figure 21. Polarized light photomicrograph of the crystal structure of butter continuously precrystallized (precrystallizing unit) at 80°F.

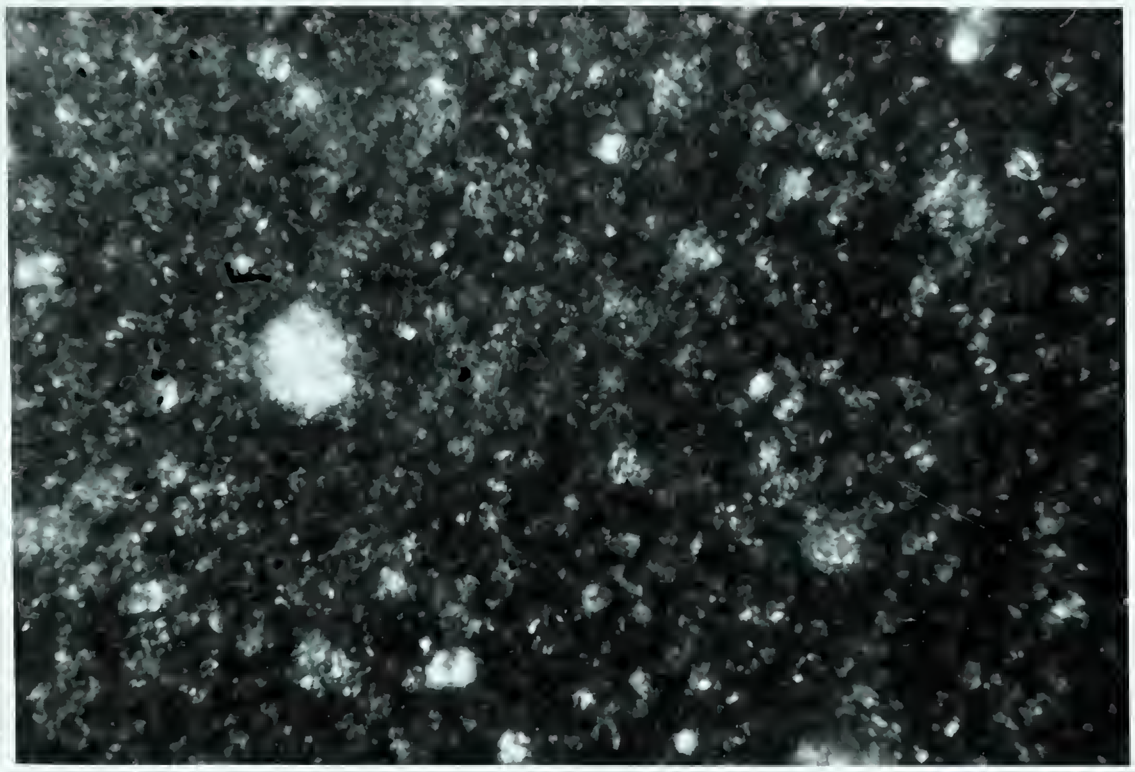

Figure 22. Polarized light photomicrograph of the crystal structure of butter continuously precrystallized (precrystallizing unit) at 70°F.

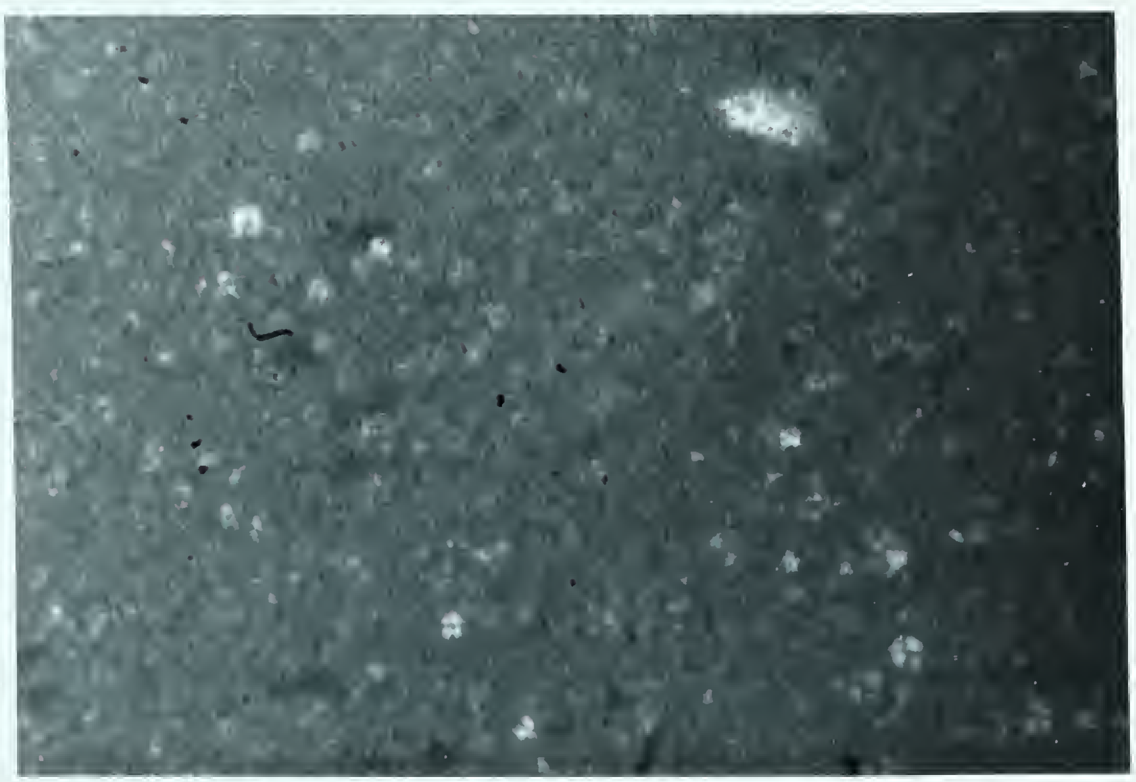

Figure 23. Polarized light photomicrograph of the crystal structure of butter continuously precrystallized (precrystallizing unit) at 60°F.

Table 13. The effect of homogenizing on the hardness of conventional butter

Trial No.	Rotor mesh	Auger r.p.m.	Hardness - ($Kg/4cm^2$) before	after	Hardness Reduction (%)
1	30	8	2.04	1.24	29.2
2	30	8	3.12	1.52	51.3
3	30	8	3.34	1.84	44.9
4	30	8	1.72	1.08	37.2
5	30	8	2.22	1.02	54.1
6	30	8	1.72	0.89	48.3
7	30	8	3.84	1.74	54.7
8	30	8	3.94	2.12	46.2
9	30	8	1.89	1.23	34.9
10	30	8	2.32	1.20	48.3
11	30	8	2.11	1.05	50.2
12	30	8	2.94	1.55	47.3
13	30 (fine)	8	2.66	1.68	36.8
14	30	18	1.96	0.88	55.1
15	30	18	1.96	1.06	45.9
17	30	18	2.12	0.83	60.8
18	30	18	2.85	1.30	54.4
27	30	18	2.36	0.90	61.9
28	30	18	2.14	0.90	57.9
29	30	18	2.14	0.96	56.1
30	30	18	2.70	0.94	65.2
31	30	18	3.28	1.81	44.8
33	30	18	3.27	1.78	45.6
34	30	18	2.47	1.22	50.6
35	30	18	2.56	1.33	48.0
37	30	18	1.87	1.26	32.6
38	30	18	2.37	1.30	45.1
39	30	18	1.84	1.02	44.6
40	30	18	2.33	1.01	56.7
41	30	18	2.86	1.42	50.3
42	30	18	2.94	1.33	54.8
16	16	18	1.96	1.04	46.9
19	16	18	2.85	1.10	61.4
20	16	18	1.62	0.92	43.2
21	16	18	2.48	0.91	63.3
22	16	18	1.56	0.74	52.6
23	16	18	2.40	0.79	59.6
26	16	18	2.36	0.78	66.9
24	16	18	2.02	1.00	50.5
32	16	18	3.28	1.74	46.9
Ave.			2.46	1.21	50.8

Table 14. The effect of homogenizing on the hardness of continuously made butter

Trial No.	Rotor mesh	Auger r.p.m.	Hardness - ($Kg/4cm^2$) before	after	Hardness Reduction (%)
60	30 (fine)	8	3.81	2.42	36.5
61	30 "	8	4.36	2.61	40.1
62	30	8	3.67	2.80	23.7
63	30	8	3.83	3.02	21.1
64	30	8	3.37	2.80	16.9
65	30	8	4.88	3.47	28.9
66	30	8	4.26	3.14	26.3
67	30	8	4.33	3.53	18.5
68	30	18	3.60	2.13	40.8
69	30	18	4.00	3.04	23.8
70	30	18	4.00	2.72	32.0
72	30	18	3.26	2.48	23.9
73	30	18	3.29	2.42	26.4
77	30	18	3.14	2.76	12.1
78	30	18	3.30	2.47	25.2
80	30	18	3.32	2.22	33.1
81	30	18	3.63	2.28	37.2
83	30	18	4.67	2.13	54.4
84	30	18	4.67	2.04	56.3
85	30	18	4.35	3.16	27.4
86	30	18	4.60	2.36	48.7
87	30	18	3.66	2.00	45.4
88	30	18	3.38	2.12	37.3
89	30	18	3.04	1.76	42.1
90	30	18	2.64	1.72	34.8
71	16 (coarse)	18	3.26	2.18	33.1
74	16	18	3.30	2.33	29.4
75	16	18	3.62	1.72	52.5
76	16	18	3.14	2.42	22.9
	Average		3.74	2.49	33.3

29 churnings of 33.3%. It is not possible to make valid comparisons of hardness differencesas a result of rotor type and auger speeds in Tables 13 and 14 as the butters used were not comparable.

A series of comparisons in which the same butter was treated by the Microfix with fine and coarse rotors (16 and 30 mesh) at the same production rate - auger speed 18 r.p.m. - are summarized in Table 15. The results for conventional butter indicate little difference in hardness reduction, though there is an indication that the coarse rotor was more effective in reducing hardness. For continuous butter on the other hand, the coarse rotor was definitely more effective in reducing hardness.

Figures 24 to 31, inclusively, are polarized light photomicrographs of the crystal structure of conventional and continuously made butter taken before and after treatment with the Microfix. These photomicrographs show clearly in each instance that there was a reduction in quantity of crystalline fat as a consequence of the homogenizing actionof the Microfix rotor. A decrease in crystal size can be observed in continuously made butter after homogenizing, (Figures 28,29,30,31) but no similar observation can be made for the conventional butters.

A limited number of experiments were set up to measure the influence of setting on the reduction of butter hardness. In these experiements the same lot of butter was processed on the day of manufacture to limit the influence of setting, and after storage for one week at two storage temperature ranges, - 21^{o} to 28^{o} and

Table 15. The effect of the coarseness of the Microfix rotor on percent hardness reduction

Trial No.	Rotor mesh	Type of butter	Hardness - ($Kg/4cm^2$) before	after	Hardness Reduction (%)
1	16	Conventional	1.96	1.04	46.9
	30			1.06	45.9
2	16	Conventional	2.85	1.10	61.4
	30			1.30	54.4
3	16	Conventional	2.36	0.78	66.9
	30			0.78	66.9
4	16	Conventional	3.28	1.74	47.0
	30			1.81	44.8
AVE.	16	Conventional	2.61	1.16	55.6
"	30			1.24	52.5
5	16	Continuous	3.26	2.18	33.1
	30			2.48	23.9
6	16	Continuous	3.14	2.42	23.9
	30			2.76	12.1
AVE.	16	Continuous	3.20	2.30	28.1
"	30			2.62	18.1

(Above tests made with an auger speed of 18 r.p.m.)

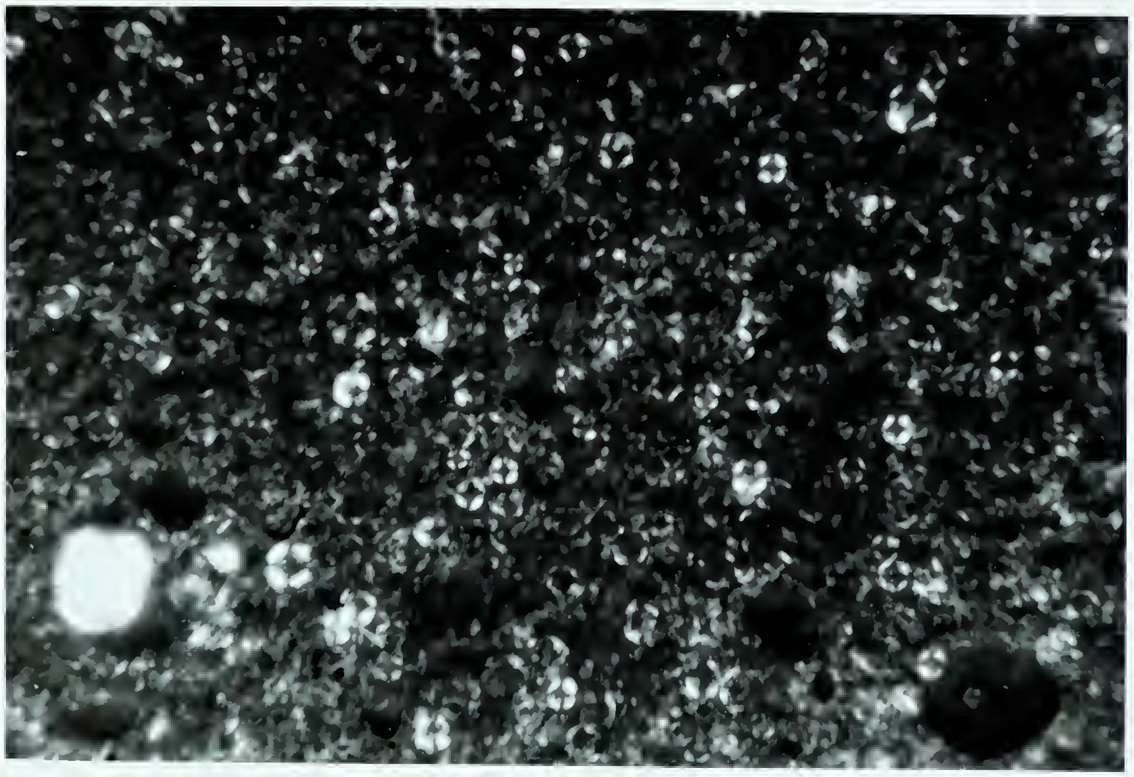

Figure 24. Polarized light photomicrograph of the crystal structure of conventional summer butter before homogenization.

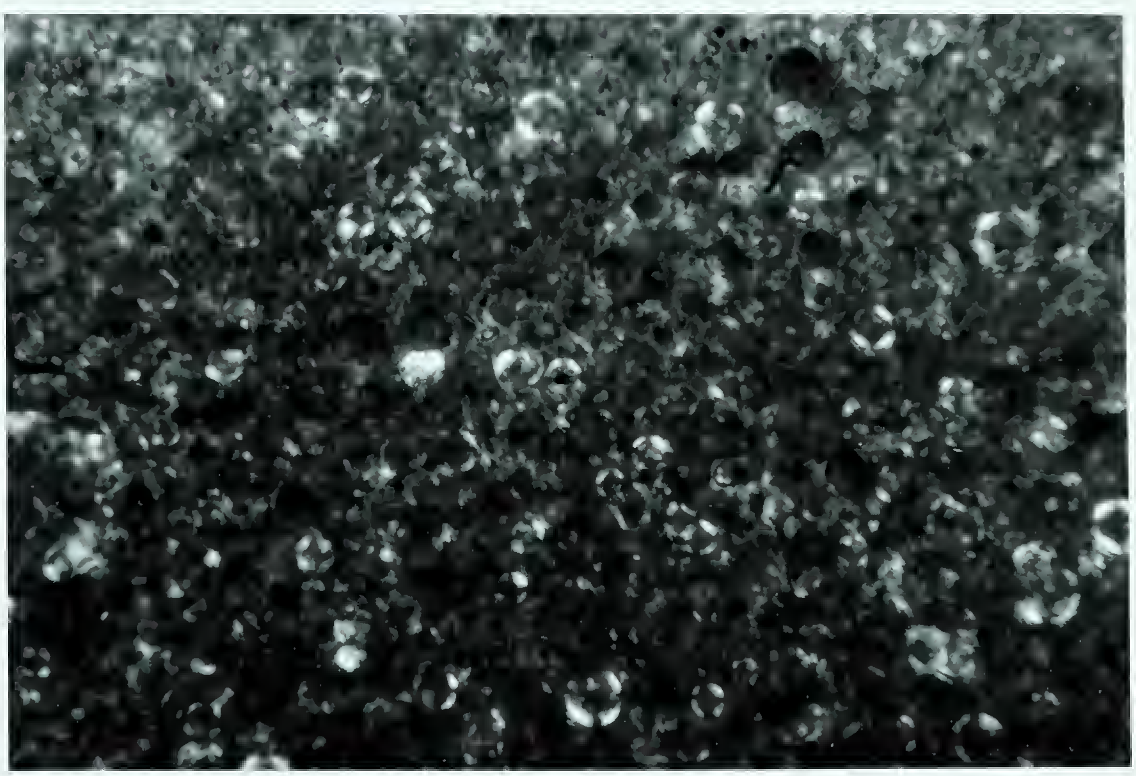

Figure 25. Polarized light photomicrograph of the crystal structure of conventional summer butter after homogenization.

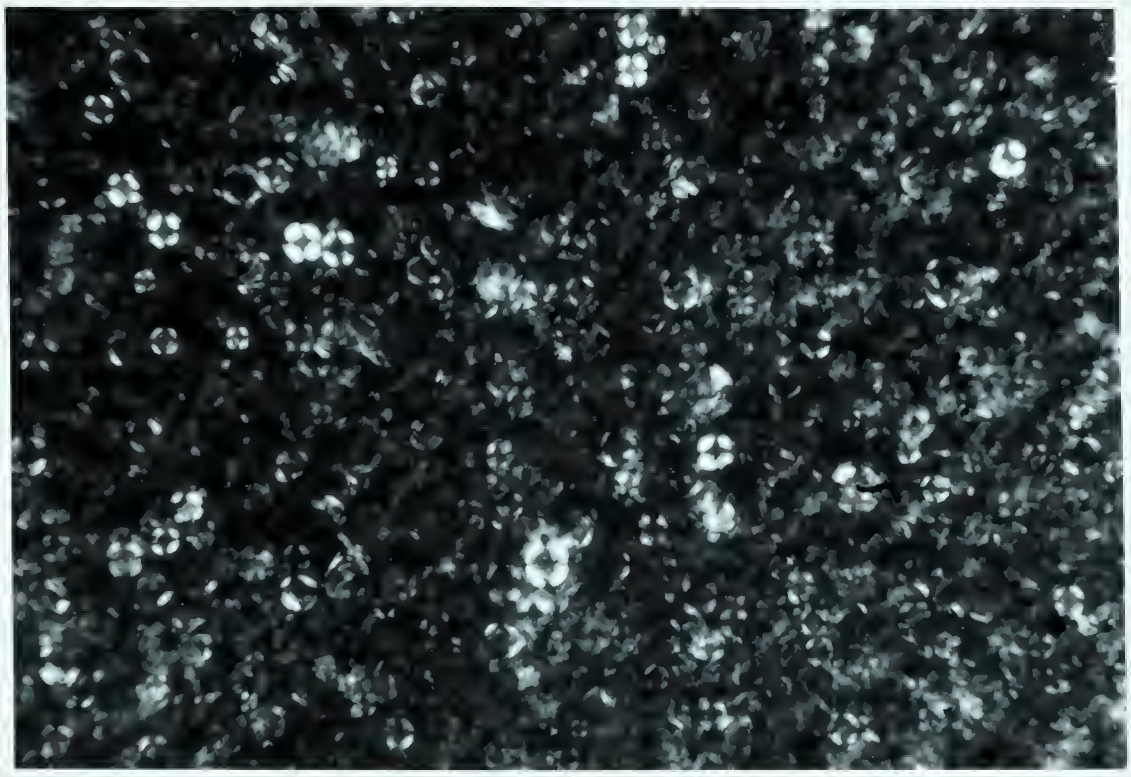

Figure 26. Polarized light photomicrograph of the crystal structure of conventional winter butter before homogenization.

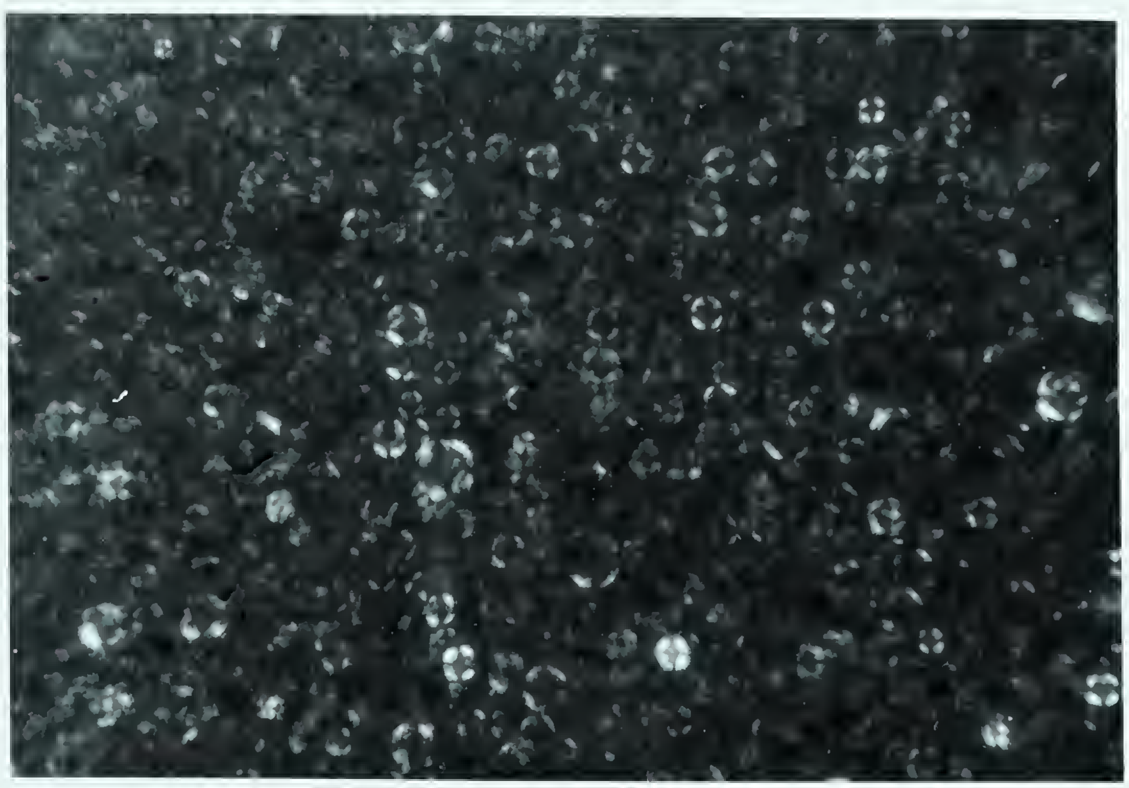

Figure 27. Polarized light photomicrograph of the crystal structure of conventional winter butter after homogenization.

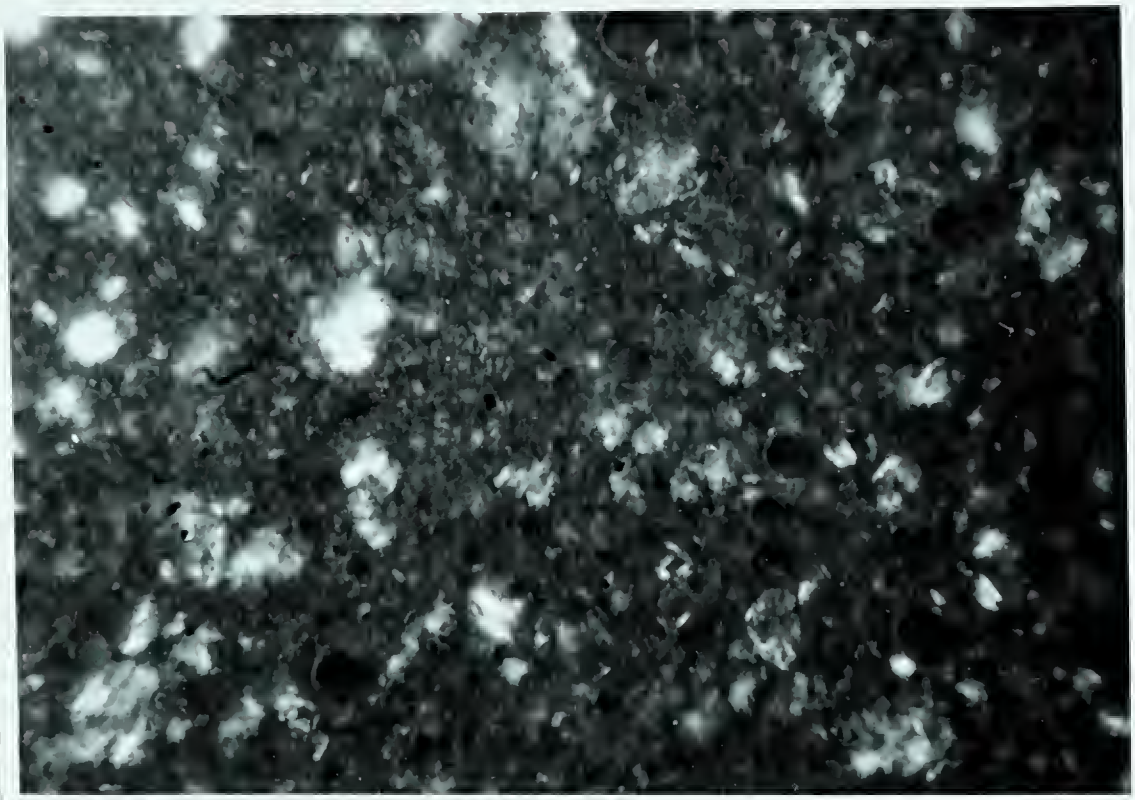

Figure 28. Polarized light photomicrograph of the crystal structure of continuously made summer butter before homogenization.

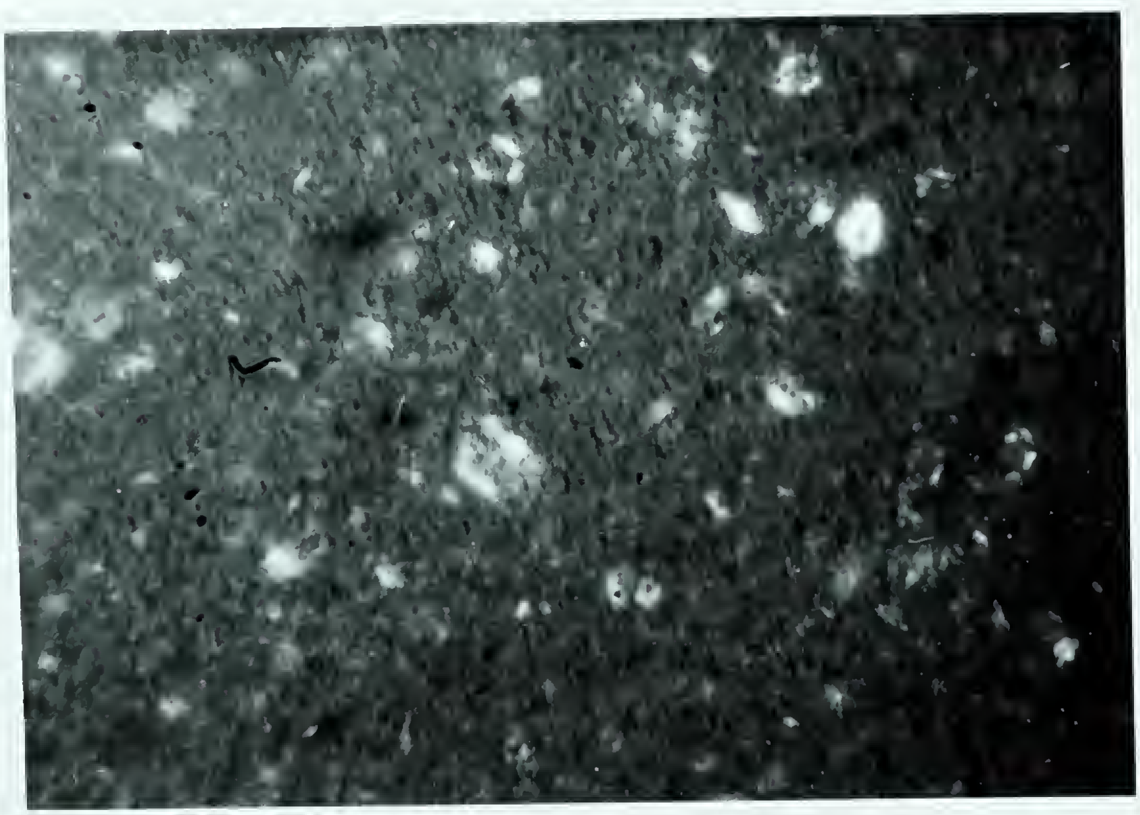

Figure 29. Polarized light photomicrograph of the crystal structure of continuously made summer butter after homogenization.

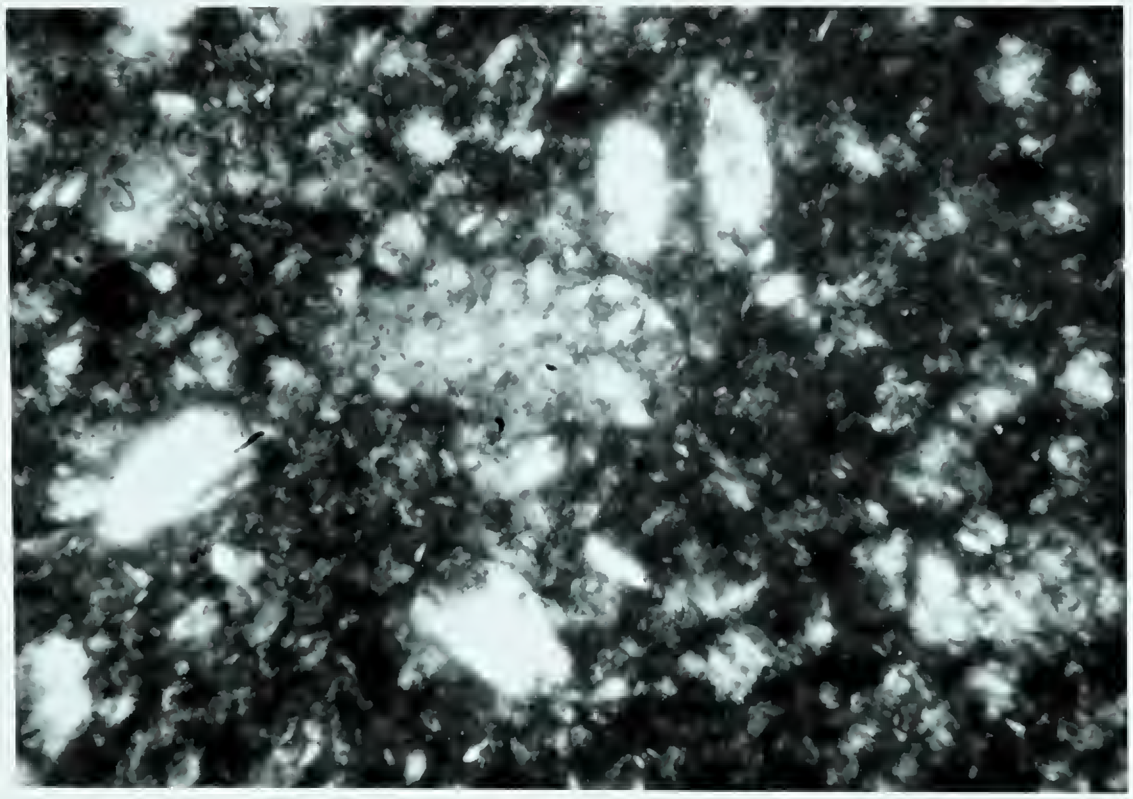

Figure 30. Polarized light photomicrograph of the crystal structure of continuously made winter butter before homogenization.

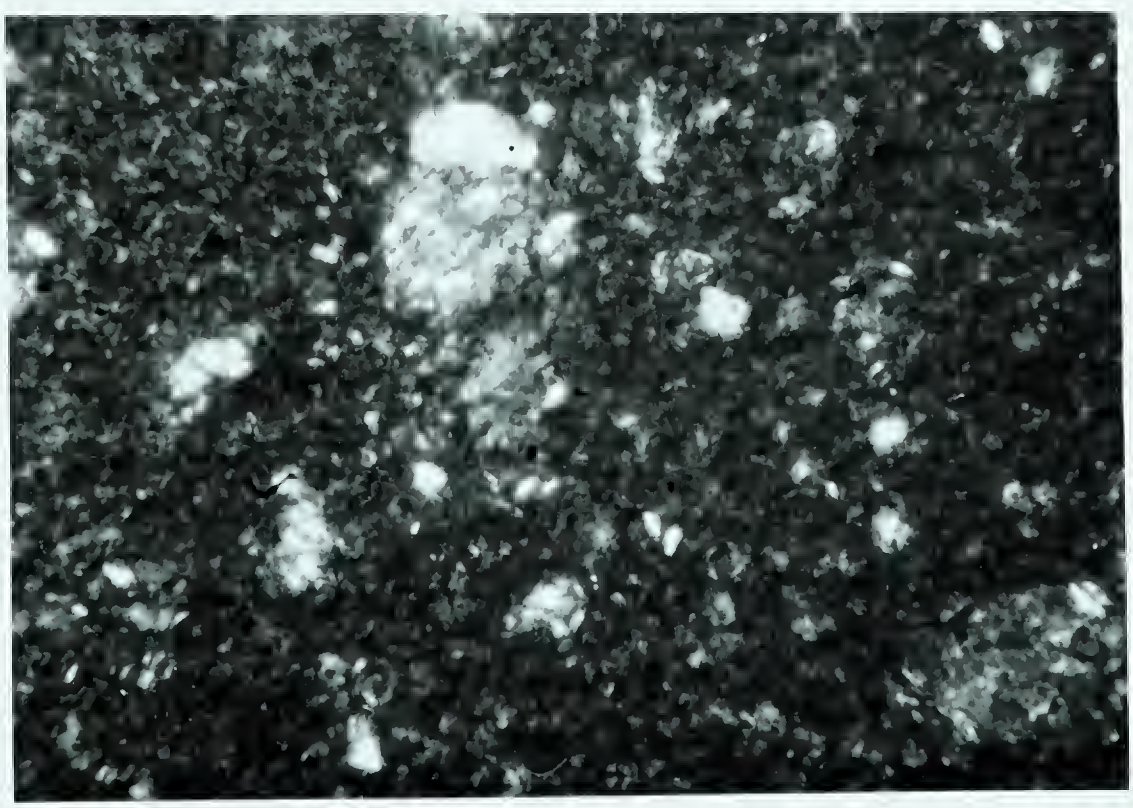

Figure 31. Polarized light photomicrograph of the crystal structure of continuously made winter butter after homogenization.

43° to 44°F. The data obtained (Table 16) show some reduction in the hardness of fresh unstored butter. This reduction was 10.5% and 10.3 to 14.5% for the conventional and continuously made butters respectively. The reduction in the hardness of butter that was stored to permit most of the hardness increase due to setting to develop, especially in the case of the conventional butter, was comparable to the values reported in Tables 13 and 14. These data also indicate that the reduction in hardness at the higher storage temperature, 43° - 44°, was as great, if not greater than that obtained at the lower storage temperature.

The influence of temperature on the effectiveness of the homogenizing process could be a very important factor in the commercial acceptance of the process. It is important to determine how extensively it is necessary to temper butter after removing it from a low temperature storage, and also to have knowledge on the extent to which it is necessary to cool butter to obtain the maximum effect of the process in hardness reduction. Pertinent information on this point has been assembled in Table 17. These data indicate that conventional butter in the temperature ranges, 20° - 29° F. and 38° - 47° F. was reduced in hardness to almost the same extent. The average values were 49.6 and 51.7% for the lower and higher temperature ranges respectively. For continuous butter the relationship was 30.4 and 35.5%, a somewhat higher reduction for the higher temperature range.

Table 16. A comparison of the hardness reduction obtained on butter treated with the Microfix immediately after manufacture and after storage for one week at two temperature levels

Trial No.	Storage Period	Storage Temp. (^oF)	Hardness - ($Kg/4cm^2$) before	after	Hardness Reduction (%)
		Conventional			
1	None	-	1.72	1.54	10.5
	One week	28	1.87	1.12	32.6
	One week	44	2.37	1.19	45.1
		Continuous			
2	None	-	3.40	3.05	10.3
	One week	28	3.32	2.22	33.1
	One week	43	3.63	2.28	37.2
3	None	-	4.56	3.90	14.5
	One week	21	4.67	2.13	54.4
	One week	43	4.67	2.04	56.3

Table 17. The effect of the homogenizing temperature on percent hardness reduction

Trial No.	Temp. of butter (°F)	Hardness - ($Kg/4cm^2$) before	after	Hardness Reduction (%)
		Conventional		
1	27	2.14	0.90	57.9
	47	2.14	0.94	56.1
2	22	3.28	1.81	44.8
	38	3.27	1.78	45.6
3	29	2.47	1.22	50.6
	42	2.56	1.33	48.0
4	23	1.84	1.02	44.6
	43	2.33	1.01	56.7
5	20	2.86	1.42	50.3
	38	2.94	1.33	54.8
	Average - (20°- 29°F)	2.52	1.27	49.6
	" (38°- 47°F)	2.65	1.28	51.7
		Continuous		
6	27	3.26	2.48	23.9
	39	3.29	2.42	26.4
7	22	3.14	2.76	12.1
	43	3.30	2.47	25.2
8	20	4.35	3.16	27.4
	38	4.60	2.36	48.7
9	24	3.66	2.00	45.4
	38	3.38	2.12	37.3
10	28	3.04	1.76	42.1
	34	2.64	1.72	34.8
	Average - (20° - 28°F)	3.49	2.43	30.4
	" (34° - 43°F)	3.44	2.22	35.5

The setting behavior of butter subsequent to the Microfix treatment was investigated by measuring the setting of the same butter before and after processing at regular intervals for a period of 4 weeks. The average results obtained on a number of samples of each type of butter are contained in Table 18. These data show a comparatively small recovery of hardness after the Microfix treatment and this is particularly evident for continously made butter. Graphs based on these data (Figure 32) effectively demonstrate the stability of the hardness decrease obtained with this process.

The oiling-off percentage of butter is a measure of the ease of oil drainage and gives information/as to the size of the butterfat crystals present in its structure. Table 19 contains a comparison of the oiling-off percentages found for both types of butter before and after treatment with the Microfix. The small increases found in butter after homogenizing were insignificant at the 5% level.

The temperature of butter increases during homogenization as the result of the severe mechanical action imparted to the butter by the rotors. Table 20 gives the average hardness, average temperature before homogenization and average temperature increase during homogenization for an equal number of conventional and continuous type butters, both of which were in the same temperature range before processing. In spite of the difference in hardness values between the conventional and continuously made butter there were no significant differences in temperature increase during homogenization.

Table 18. The extent of hardness increases subsequent to the Microfix treatment of representative summer and winter butters

Days of Storage	Ave. Hardness - ($Kg/4cm^2$) before	after	Hardness increase (%)
	Conventional*		
1	1.86	0.98	-
7	2.19	1.04	6.1
14	2.34	1.09	11.2
28	2.57	1.21	23.5
	Continuous**		
1	4.10	2.55	-
7	4.42	2.72	6.7
14	4.48	2.77	8.6
28	4.55	2.93	11.0

* Average based on 6 butters

** Averages based on 3 butters

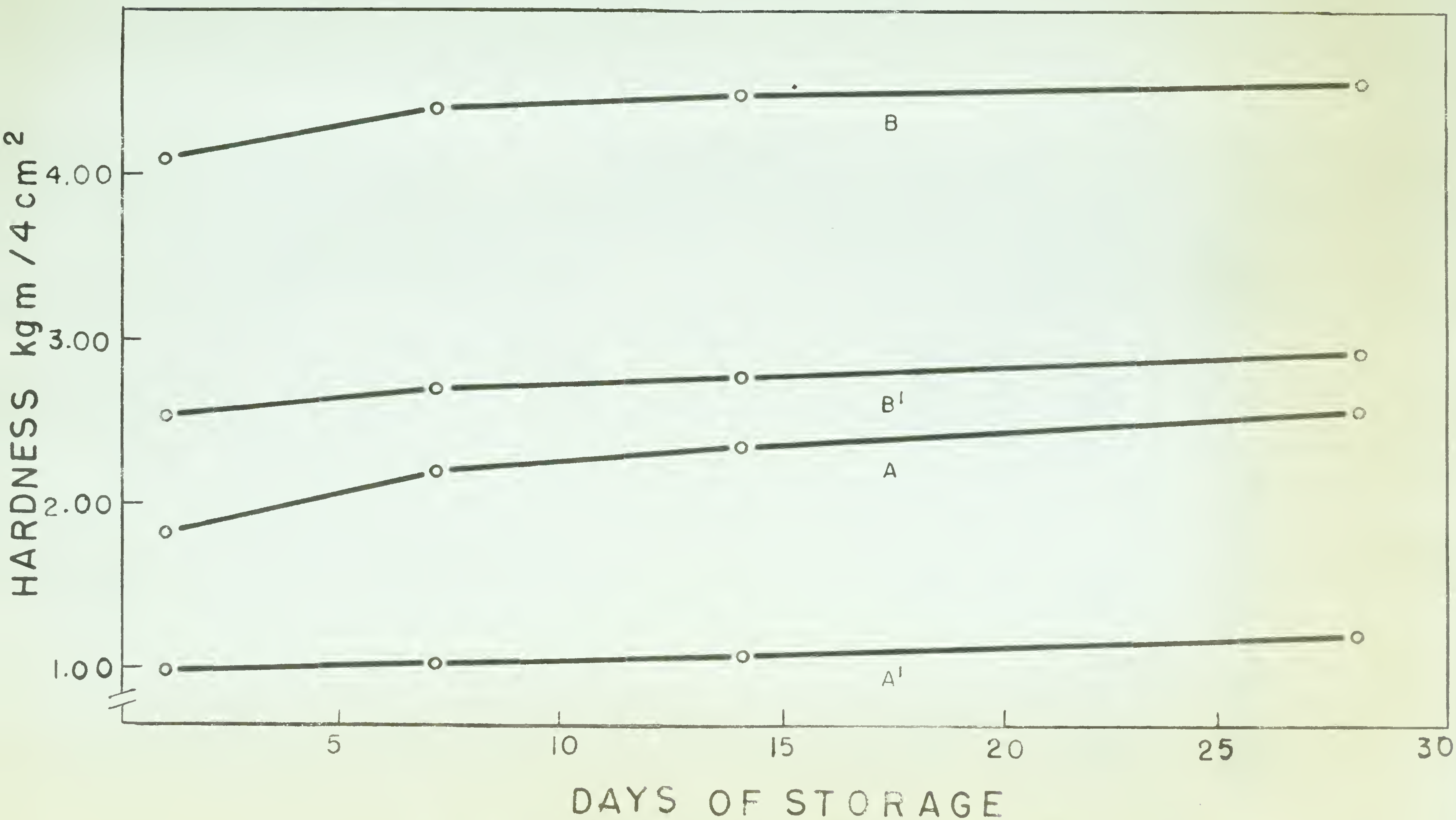

Figure 32. The average increase in hardness of homogenized and unhomogenized butter.
- conventional butter, unhomogenized (curve A)
- same butter, homogenized (curve A^1)
- continuously made, unhomogenized (curve B)
- same butter, homogenized (curve B^1)

Table 19. A comparison of the average oiling-off percentage of conventional and continuous butter before and after homogenization

No. of Trials	Type of butter	Ave. Oiling-off (%) before	Ave. Oiling-off (%) after
37	Conventional	8.7	8.9
29	Continuous	10.6	10.7

Table 20. The effect of type, hardness and temperature of butter on temperature increase during homogenization.

No. of trials	Type of butter	Ave. hardness before homogenization $kg/4cm^2$	Range of temp. ^{o} F.	Ave. temperature ^{o}F before homogenization	increase
11	Conventional	2.83	40 or less	28.1	22.3
11	Continuous	3.80	40 or less	27.7	24.0
9	Conventional	2.63	$>$ 40	44.0	11.4
9	Continuous	4.10	$>$ 40	44.4	12.3

All conventional butters contain some gas while continuously made butter contains no gas unless it is added during processing. A limited number of trials were carried out to determine if the homogenizing treatment affected the gas content of butter (Table 21). The average gas content of conventional butter was reduced from 2.8 to 1.4%, while the average gas content of continuously made butter was increased from 0.0 to 0.3%. Trials 1 and 7 showed no reduction of gas content.

Table 21. The effect of homogenization on the gas content of butter

Trial No.	Gas content (%) before	after
	Conventional	
1	3.3	3.3
2	2.9	1.6
3	3.7	0.7
4	3.0	0.7
5	2.9	1.2
6	1.8	0.8
7	1.7	1.7
Average	2.8	1.4
	Continuous	
8	0.0	0.5
9	0.0	0.4
10	0.0	0.1
11	0.0	0.0
12	0.0	0.1
Average	0.0	0.3

DISCUSSION

Hardness Variability of Bulk Butter in Seven Pound Grading Samples.

In order to obtain a measure of the hardness variability of unprinted bulk packed butter, as it is presented for grading, determinations were made without removing the butter from the package by the unmodified penetrometer method of Kruisheer & den Herder. (1938). The data obtained over the period of a year for the hardness of butter from five creameries in the Edmonton area are shown in Figure 6 and the variability has been discussed. With the exception of the butter from creamery D, the variability obtained was greater than expected and indicated that much effort must be expended to determine how much of the hardness variability is caused by faulty processing techniques. Some of the faulty processing techniques which have been shown to contribute to excessive hardness in butter were referred to in the review of literature. Coulter & Combs (1938) found that cooling of cream to a low temperature, rapid cooling to below 40^{o}F., and churning at a low temperature increased butter hardness. Dolby (1941b) stated that rapid cooling of cream yielded consistently harder butter. It is evident from the data of the present research and the investigations of Coulter & Combs, and Dolby that improvements in processing technique could reduce excessive hardness and hardness variability to a considerable extent. In this connection the wide seasonal variation and generally high hardness value obtained in the butter from creamery B are interesting. This creamery is equipped with a Vacreator (vacuum pasteurizer) which is known to cause a considerable de-stabilization of the butterfat globules, with a consequent

greater loss of butterfat in the buttermilk. The greater hardness of butter made from Vacreator pasteurized cream has been a practical observation since the introduction of the method for pasteurization of cream in our creameries, and Reinart & Nesbitt (1959) reported work in which they found a significantly greater hardness for this type of butter. The presence of a considerable quantity of destabilized butterfat in Vacreator pasteurized cream could easily contribute to the formation of larger butterfat crystals during the cooling of the cream and cause an increase in the hardness of the butter.

The testing of butter in bulk packages in these tests indicates that the method of Kruisheer & den Herder (1938) might have general application in testing the hardness of butter at the time it is graded. The principle difficulty experienced was in maintaining the butter at a uniform temperature. This may require grading rooms equipped with better temperature control. Kruisheer & den Herder have prepared curves for making corrections when it is necessary to make tests over a range of temperatures. These curves were checked and found to be applicable under our conditions and they were applied to the data presented in Figure 6 and Tables 1 and 2.

Retail samples of butter and margarine.

The high level of hardness of the margarine samples was comparable to the hardness found in the samples of continuous butter, which is made by a similar manufacturing process. The margarines varied considerably in hardness throughout the time they were being

tested, but the average hardness of all the brands tested was higher than the average obtained for the brands of butter with the exception of the brand of continuous butter. The polarized light photomicrographs, Figures 9 and 10 for hard and soft margarines respectively, clearly show a distinctly smaller crystal size and small crystalline content in the soft margarine. The hard margarine has much larger crystals that are similar to those found in the continuous butter (Figure 7). The results obtained in the chemical analysis of the butterfats and margarine oils were distinctly different, as was expected, but the softening points and the melting points of the high melting point glycerides are remarkably similar and indicate that the problem of improving the spreadability of both products through reductions in hardness are similar.

These tests on market brands of margarine and butter indicate that problems of spreadability exist in both products. It seems clear that the impression created by some manufacturers of margarine that their products are always easily spread at refrigerator temperature, must be without foundation in fact. However this does not imply that some soft margarines are not manufactured but it does show that based on the results obtained in this study, margarine is still as variable as butter in hardness.

The similarity found in the melting points of the high melting point glycerides of the margarines oils and butterfat indicates

that the precrystallization process applied in their manufacture should be effective in reducing the hardness of both products.

Precrystallization.

Precrystallization experiments with an ice refrigerated cooling coil and commercial batch procedures were of an exploratory nature. With the cooling coil procedure, the residence time of the butterfat was apparently insufficient to permit precrystallization. In the batch procedures, precrystallization occurred and the hardness of the butter was effectively reduced but the product, particularly under the commercial scale operation was unacceptable because of a grainy texture and an excessive oiling-off condition. Only the redesigned laboratory continuous buttermaking unit produced a butter with a reduced hardness that was otherwise acceptable.

In this research, the effect of the precrystallization of butterfat on the hardness of continuously made butter has been demonstrated. This reduction in hardness was anticipated as a consequence of the investigations reported by Mulder (1953) in which he reports that step-wise cooling reduces the tendency for mixed crystal formation and the total quantity of crystalline or solid butterfat in cream. Recently this observation has been confirmed by deMan (1960b) for butterfat. The step-wise cooling or precrystallization of the butterfat concentrate in the present research, on the basis of the observations of both Mulder and deMan must have removed the high melting point glycerides and consequently lowered the final solid butterfat content of the butter

to produce a softer product.

In this investigation the precrystallization temperatures obtained in the precrystallizing unit were limited to those that could be obtained at three pump speeds and by the capacity of the precrystallizing unit. It was found difficult to obtain positive control of the temperature in the precrystallizing chamber. The results (Table 12) show that the most effective reduction in the hardness of the butter was obtained in the temperature range of 70° - 75°F., under the conditions of concentrate residence provided by the precrystallizing unit. The results obtained at temperatures above 75°F show a smaller reduction of hardness presumably because these conditions did not permit sufficient crystallization of the high melting point glycerides to take place. For temperatures below 70°F the reduction of hardness was also less, indicating less reduction of the mixed crystal content in the butter.

Polarized light photomicrographs of the crystalline structure of butter made from non-precrystallized and precrystallized concentrate show the presence of rather large crystals in the butter made from the laboratory and commercial batch precrystallized concentrate. Maintaining the temperature of butterfat where some of the fat can crystallize, under quiescent conditions favors the formation of large crystals. The significance of these crystals is not known. Their appearance in the butter from the commercial batch precrystallized concentrate seems to have been associated with

the presence of a grainy texture, while both types showed an abnormal oiling-off percentage. The presence of similar, but much smaller crystals in the butter made from the butterfat precrystallized at approximately 80° or 70°F in the precrystallizing unit was not accompanied by either a grainy texture or an abnormal oiling-off condition. The normal oiling-off percentage obtained on these butters indicate that the crystalline structure cannot be much coarser than that found in normal continuously made butter. A careful examination of the photomicrographs does not reveal any obvious change in the crystalline content as a consequence of precrystallization.

The Homogenization of Butter.

The effective reduction of the hardness of both conventional and continuous butter by homogenizing it with a Microfix unit leads to speculation as to the manner in which this reduction is accomplished and particularly why the reduction was so permanent over a period of four weeks.

It is unlikely that the homogenizing process would cause a reduction in the quantity of solid or crystalline butterfat. The only alternative explanation for a reduced hardness must be based on the disruption of the crystal structure or a change in the size and/or shape of the individual crystals. In comparing the hardness of conventional and continuously made butters, deMan & Wood (1958d) point out that butter consists of a primary and secondary structure.

Continuously made butter consists mainly of a primary structure made up of relatively large crystals and comparatively little secondary structure formed by setting of the butter, which involves crystals of the order of 1 μ or less. Conventional butter on the other hand, is made up of less primary structure and more secondary structure which is formed from the large amount of very small fat crystals released from fat globules, disrupted during churning and working.

The data contained in Table 16 shows that the hardness of fresh butter is not greatly reduced by homogenization as the reduction obtained for both types of butter is less than 15%. The uniformity of this hardness reduction for both butter types is surprising as it indicates that the hardness reduction in fresh butter is not in proportion to the amount of primary structure, which is much greater in continuously made butter. Storage for one week is apparently sufficient to attain maximum hardness reduction. This storage period allows essentially all of the hardness increase due to setting to be completed.

The degree to which hardness failed to recover after homogenization was unexpected and difficult to account for except on the basis of an overall increased size of the smaller fat crystals, which would tend to eliminate hardness increase through setting. Loss of hardness through destruction of the primary structure is more easily comprehended. There is plausible explanation for an increase in fat crystal size as a consequence

of homogenization and that is the rapid rise in the temperature of the butter in the head of the Microfix - 11.4° to 24.0°F (Table 20). This increase in temperature of the butter might preferentially melt small fat crystals and cause those that were left to increase in size as the butter cooled. The photomicrographs of the butter taken subsequent to the homogenization process indicate a decrease in the quantity of crystallized butterfat but this could be an illusion causedby a small change in the relative size of the fat crystals.

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